# Eastern Bering Sea
# Walleye Pollock Stock Assessment

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## Summary

The primary focus of this chapter is on the eastern Bering Sea region. The Aleutian Islands region and Bogoslof Island area are treated separately in Sections 1.15 and 1.16.

*Changes in the input data*
The 2002 NMFS bottom-trawl survey estimates of population numbers-at-age were available for analysis in this assessment. The biomass estimate for 2002 is 4.82 million tons, an increase of 16% from the 2001 estimate of 4.14 million tons. For the echo-integration trawl (EIT) surveys the 2002 biomass estimate for the region is 3.6 million tons, an 18% increase over the 2000 estimate (the last year an EIT survey was conducted). Samples of pollock otoliths from the bottom trawl survey were examined for age determination and an estimate of the numbers-at-age from this survey were computed and used in the analysis. For the EIT survey, the otolith samples have not yet been processed. Therefore, we applied the age-length key constructed from the bottom-trawl survey collections to the EIT length composition estimates. We used these preliminary estimates of the 2002 numbers-at-age from the EIT survey within the assessment analysis.

The NMFS observer samples of pollock age and size composition were evaluated for the 2001 fishery and these data were included in the analyses. The estimates of average weight-at-age from the fishery were also revised. The total catch estimate was updated for 2001. For 2002, we assumed that the catch is equal to the 2002 TAC (1,485,000 t).

*Changes in the assessment model*
No major changes to the assessment model were made this year. As in past years, an array of model alternatives were performed and evaluated for contrast.

*Changes in the assessment results*
Compared to last year's estimates, the 2001 biomass level is about 6% higher due to increases in the estimates of the age 9 and older pollock. Also, the estimates of the 1999 and 2000 year classes increased and appear to be average or above-average in magnitude.

The 2003 maximum ABC alternatives based on the $F_{40\%}$ and $F_{msy}$ are 2,322 and 2,327 thousand tons, respectively for the reference model ($F_{msy}$ harvests based on the harmonic mean value). As with last year, a lower value for the $F_{msy}$ value reflects the level of uncertainty about stock size. The 2003 overfishing level (OFL) alternatives for the reference model are 2,869 and 3,532 thousand tons corresponding to $F_{35\%}$ and $F_{msy}$ (arithmetic mean). Stock levels appear to be relatively high for EBS pollock, but a large degree of uncertainty in the estimates remains.

In the summer of 2002, NMFS conducted a bottom-trawl survey throughout the Aleutian Islands region. The estimate of on-bottom pollock in the Aleutians from this survey is **175,283 t**, up considerably from the 2000 estimate of 105,554 t. This gives **ABC** and **OFL values of 39,438 t** and **52,585 t,** respectively.

For the Bogoslof region, we followed the SSC recommendations and compute maximum permissible ABC and OFL based on Tier 5. This results in **33,982 t** and **45,309 t** for ABC and OFL, respectively. Following SSC recommendations reduced the ABC relative to the target stock size (2 million tons). This gives a 2003 ABC of **4,074 t** for the Bogoslof Island region.

## 1.1. Introduction

### 1.1.1. Stock structure

In the U.S. portion of the Bering Sea pollock three stocks are identified for management purposes. These are: eastern Bering Sea which consists of pollock occurring on the eastern Bering Sea shelf from Unimak Pass and to the U.S.-Russia Convention line; the Aleutian Islands Region encompassing the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and the Central Bering Sea—Bogoslof Island pollock. These three management stocks undoubtedly have some degree of exchange. The Bogoslof stock is a group that forms a distinct spawning aggregation that has some connection with the deep water region of the Aleutian Basin. In the Russian EEZ, pollock are considered to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line. The northern stock is believed to be a mixture of eastern and western Bering Sea pollock with the former predominant. Bailey et al. (1999) present a thorough review of population structure of pollock throughout the north Pacific region. Recent genetic studies using mitochondrial DNA methods have found the largest differences to be between pollock from the east and western sides of the north Pacific. Stocks that are in close proximity share similar genetic characteristics (M. Canino, AFSC/NOAA, pers. comm.). In October of 2002 at the 11$^{th}$ PICES meeting a special session on pollock resources was convened. This session provided an open forum for discussing hypotheses on pollock stock-structure issues. In particular, the interaction of pollock abundance with environmental conditions was a common theme throughout the session.

## 1.2. Catch history and fishery data

From 1954 to 1963, pollock were harvested at low levels in the Eastern Bering Sea and directed foreign fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970-75 when catches ranged from 1.3 to 1.9 million t annually (Fig. 1.1). Following a peak catch of 1.9 million t in 1972, catches were reduced through bilateral agreements with Japan and the USSR.

Since the advent of the U.S. EEZ in 1977 the annual average eastern Bering Sea pollock catch has been 1.2 million t and has ranged from 0.9 million t in 1987 to nearly 1.5 million t (including the Bogoslof Islands area catch; Fig. 1.1). Stock biomass has apparently ranged from a low of 4-5 million t to highs of 10-12 million t. United States vessels began fishing for pollock in 1980 and by 1987 they were able to take 99% of the quota. Since 1988, only U.S. vessels have been operating in this fishery. By 1991, the current NMFS observer program for north Pacific groundfish-fisheries was in place.

Foreign vessels began fishing in the mid-1980s in the international zone of the Bering Sea (commonly referred to as the “Donut Hole”). The Donut Hole is entirely contained in the deep water of the Aleutian Basin and is distinct from the customary areas of pollock fisheries, namely the continental shelves and slopes. Japanese scientists began reporting the presence of large quantities of pollock in the Aleutian Basin in the mid-to-late 1970's, but large scale fisheries did not occur until the mid-1980's. In 1984, the Donut Hole catch was only 181 thousand t (Fig. 1.1, Table 1.1). The catch grew rapidly and by 1987 the high seas catch exceeded the pollock catch within the U.S. Bering Sea EEZ. The extra-EEZ catch peaked in 1989 at 1.45 million t and has declined sharply since then. By 1991 the donut hole catch was 80% less than the peak catch, and data for 1992 and 1993 indicate very low catches (Table 1.1). A fishing moratorium was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin by resource assessment fisheries.

### 1.2.1. Fishery characteristics

The pattern of the modern fishery (since the early 1990s) has been to focus on a winter, spawning-aggregation fishery (the "A-season) with an opening on January 20th. This first season typically lasts about 4-6 weeks, depending on the catch rates. A second season opening has occurred on September 1st (though 1995 opened on Aug 15th). This has changed considerably over the past few years and management has focused on minimizing the possibility that the pollock fishery inhibits the recovery of the Steller sea lion population or adversely modifies their habitat. We discuss this in detail in the next section.

Since the closure of the Bogoslof management district (INPFC area 518) to directed pollock fishing in 1992, the "A-season" (January – March) pollock fishery on the eastern Bering Sea (EBS) shelf has been concentrated primarily north and west of Unimak Island (Ianelli *et al.* 1998). Depending on ice conditions and fish distribution, there has also been effort along the 100 m contour between Unimak Island and the Pribilof Islands. This pattern has gradually changed during the period 1999 - 2002 (Fig. 1.2). The total catch estimates by sex for the A-season compared to the fishery as a whole indicates that over time, the number of males and females has been fairly equal with a slight tendency to harvesting males more than females in recent years (Fig. 1.3). The length frequency information from the fishery shows that the size of pollock is generally larger than 40 cm but with some smaller fish caught during years when a strong year class appeared (Fig. 1.4).

After 1992, the "B-season" (typically September – October) fishery has been conducted to a much greater extent west of 170°W than it had been prior to 1992 (Ianelli *et al.* 1998). This shift was due to the implementation of the CVOA (Catcher Vessel Operational Area) in 1992 and also the geographic distribution of pollock by size. The pattern in the past few years shows an increase in this trend (towards catching pollock west of 170°W) and decreasing amounts within the Sea lion conservation area (SCA) until this year. Concentrated removals occurred within the SCA in the second halves of 2001 and 2002 compared to 2000 (Fig. 1.5). However, the 2002 catch seems more evenly distributed within the SCA compared to 2000.

The length frequency information from the fishery reveals a marked progression of the large 1989 year class growing over time and the appearance of the 1992 year class in 1996-97 and subsequent 1996 year class in 1998-2002 (Fig. 1.6).

### 1.2.2. Fisheries Management

In response to continuing concerns over the possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions, NMFS and the NPFMC have made changes to the Atka mackerel (mackerel) and pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). These have been designed to reduce the possibility of competitive interactions with Steller sea lions. For the pollock fisheries, comparisons of seasonal fishery catch and pollock biomass distributions (from surveys) by area in the eastern Bering Sea (EBS) led to the conclusion that the pollock fishery had disproportionately high seasonal harvest rates within critical habitat which *could* lead to reduced sea lion prey densities. Consequently, the management measures were designed to redistribute the fishery both temporally and spatially according to pollock biomass distributions. The underlying assumption in this approach was that the independently derived area-wide and annual exploitation rate for pollock would not reduce local prey densities for sea lions. Here we examine the temporal and spatial dispersion of the fishery to evaluate the potential effectiveness of the measures.

Three types of measures were implemented in the pollock fisheries:

- Additional pollock fishery exclusion zones around sea lion rookery or haulout sites,
- Phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat, and
- Additional seasonal TAC releases to disperse the fishery in time.

Prior to the management measures, the pollock fishery occurred in each of the three major fishery management regions of the north Pacific ocean managed by the NPFMC: the Aleutian Islands (1,001,780 $km^2$ inside the EEZ), the eastern Bering Sea (968,600 $km^2$), and the Gulf of Alaska (1,156,100 $km^2$). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 $km^2$ of ocean surface, or 12% of the fishery management regions.

Prior to 1999, a total of 84,100 $km^2$, or 22% of critical habitat, was closed to the pollock fishery. Most of this closure consisted of the 10 and 20 nm radius all-trawl fishery exclusion zones around sea lion rookeries (48,920 $km^2$ or 13% of critical habitat). The remainder was largely management area 518 (35,180 $km^2$, or 9% of critical habitat) which was closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock.

In 1999, an additional 83,080 $km^2$ (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 $km^2$ (11%) around sea lion haulouts in the GOA and eastern Bering Sea. Consequently, a total of 210,350 $km^2$ (54%) of critical habitat was closed to the pollock fishery. The portion of critical habitat that remained open to the pollock fishery consisted primarily of the area between 10 and 20 nm from rookeries and haulouts in the GOA and parts of the eastern Bering Sea foraging area.

The Bering Sea/Aleutian Islands pollock fishery was also subject to changes in total catch and catch distribution. Disentangling the specific changes in the temporal and spatial dispersion of the EBS pollock fishery resulting from the sea lion management measures from those resulting from implementation of the American Fisheries Act (AFA) is difficult. The AFA reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector by 2000. Both of these changes would be expected to reduce the rate at which the catcher/processor sector (allocated 36% of the EBS pollock TAC) caught pollock beginning in 1999, and the fleet as a whole in 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation that otherwise could have been more disruptive to the industry.

In 2000, further reductions in seasonal pollock catches from BSAI sea lion critical habitat were realized by closing the entire Aleutian Islands region to pollock fishing and by phased-in reductions in the proportions of seasonal TAC that could be caught from the Sea Lion Conservation Area, an area which overlaps considerably with sea lion critical habitat. In 1998, over 22,000 t of pollock were caught in the Aleutian Island regions, with over 17,000 t caught in AI critical habitat. Since 1998 directed fishery removals of pollock have been prohibited.

On the eastern Bering Sea shelf, an estimate (based on observer at-sea data) of the proportion of pollock caught in critical habitat has averaged 35% since the 1998 estimate of 60%. Preliminary estimates for 2002 indicate a higher proportion of pollock caught within the SCA compared to 1999-2001:

| Year | Months | Catch Outside SCA | Total Catch | Percent Inside SCA |
|---|---|---|---|---|
| 1998 | Jan-Jun | 71 | 385 | 82% |
| | Jul-Dec | 248 | 403 | 39% |
| | Jan-Dec | 318 | 788 | 60% |
| 1999 | Jan-Jun | 155 | 339 | 54% |
| | Jul-Dec | 360 | 468 | 23% |
| | Jan-Dec | 515 | 807 | 36% |
| 2000 | Jan-Jun | 241 | 375 | 36% |
| | Jul-Dec | 550 | 572 | 4% |
| | Jan-Dec | 791 | 947 | 16% |
| 2001 | Jan-Jun | 343 | 475 | 28% |
| | Jul-Dec | 368 | 642 | 43% |
| | Jan-Dec | 711 | 1,116 | 36% |
| 2002 | Jan-Jun | 262 | 562 | 53% |
| | Jul-Dec | 346 | 627 | 45% |
| | Jan-Dec | 609 | 1,189 | 49% |

*Note: Pollock catches (thousands of tons) are as reported by at-sea observers only, 2002 data are preliminary.*

An additional goal for minimizing the potential for impacting the sea lion population is to disperse the fishery throughout more of the pollock range on the eastern Bering Sea shelf. While the distribution of fishing during this time of year is limited due to ice and weather conditions, there appears to be some dispersion to the northwest area (Fig. 1.2).

Seasonal TAC releases were intended to disperse the fishery throughout more of the year. Prior to the increased sea lion conservation measures, the fishery was concentrated in 2 seasons, each approximately 6 weeks in length in January-February, and September-October; 94% of the pollock fishery occurred during these four months, with 45% in January-February and 49% in September-October. In 1999, the measures dispersed the early fishery into March (which reduced the percentage taken in February) and the later fishery into August, but very little into the April-July period. Also relevant to current management measures are examinations of historical patterns of pollock fishing. For this we compiled foreign observer data by month for each year and computed the geographic center of where the removals occurred. Results show that the fishing patterns in the 1980s were quite different than in the 1990s. There appears to be much greater separation between fishing in the early and later seasons within a year during the 1990s while during the 1980s, there appears to be very similar centers of catch distributions in both early and late seasons (Fig. 1.7). This could be partly due to differences in observer coverage and changes to pelagic gear during the 1990s.

### 1.2.3. Catch data

Significant quantities of pollock are discarded and must be taken into account in estimation of population size and forecasts of yield. Observer length frequency observations indicated that discarded pollock include both large and small pollock. Since observers usually sample the catch prior to discarding, the size distribution of pollock sampled closely reflects that of the actual *total* catch. Discard data as compiled by the NMFS Alaska Regional Office have been included in estimates of total catch since 1990.

Pollock catch in the eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch, 1990-2001 are shown in Table 1.2. Since 1990, estimates of discarded pollock have ranged from a high of 11% of total pollock catch in 1991 to a low of 1.3% in 2001. These recent low values reflect the implementation of the Council's Improved Utilization and Improved Retention program. Discard rates are likely affected by the age-structure and relative abundance of the available population. For example, if the most abundant year class in the population is below marketable size, these smaller fish may be caught incidentally. With the implementation of the AFA, the fleets have more time to pursue the sizes of fish they desire since they are guaranteed a fraction of the quota. In addition, several vessels have made gear modifications to avoid retention of smaller pollock. In all cases, the magnitude of discards is accounted for within the population assessment and for management (to ensure the TAC is not exceeded).

We estimate the catch-at-age composition using the methods described by Kimura (1989) and modified by Dorn (1992). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: 1) INPFC area 51 from January - June; 2) INPFC area 51 from July -December; and 3) INPFC area 52 from January - December. This method was used to derive the age compositions from 1991-2000 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch - age composition estimates as presented in Wespestad *et al.* (1996).

The time series of the catch proportions-at-age suggests that during 1999-2001 a broad range of age groups were harvested with a continued strong showing of the 1992, 1995, and 1996 year classes (Fig. 1.8). We present these values (as used in the age-structured model) from 1979-2001 in Table 1.3. Since 1999 the observer program adopted a new sampling strategy for lengths and age-determination studies. Under this scheme, more observers collect otoliths from a greater number of hauls (but far fewer specimens per haul). This has improved the geographic coverage but lowered the total number of otoliths collected. Previously, large numbers were collected but most were not aged. The sampling effort for lengths has decreased since 1999 but the number of otoliths processed for age-determinations increased (Table 1.4). Also, we qualitatively evaluated the proportional allocation of sampling effort for pollock catch, length, and age samples (Fig. 1.9). This shows that there doesn't appear to be much discrepancy between allocation percentages for length measurements and otolith collections relative to catch locations. As part of a study to evaluate the effectiveness of the new sampling protocol, observers in 1999 also collected data using the "old" method. A study is currently underway analyzing the impact of changing the observer otolith collection scheme and we anticipate results from these analyses to be completed prior to next year's assessment.

## 1.3. Resource surveys

This year, scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 1999) from NMFS surveys in the Bering Sea and Aleutian Islands Region (tons):

| Year | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bering Sea | 15 | 94 | 458 | 139 | 466 | 682 | 508 | 208 | 435 | 163 | 174 | 467 | 393 |
| Aleutian Is. | | | | 193 | | 40 | 454 | | | 292 | | | |

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bering Sea | 369 | 465 | 156 | 221 | 267 | 249 | 206 | 262 | 121 | 162 | NA | NA | NA |
| Aleutian Is. | | 51 | | | 48 | | | 36 | | | NA | NA | NA |

Since these values represent extremely small fractions of the total removals (~0.02%), they are not explicitly added to the total removals by the fishery.

### 1.3.1. Bottom trawl surveys

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea. Bottom trawl surveys are considered to assess pollock from the bottom to 3 m off bottom. Until 1975 the survey only covered a small portion of the pollock range. In 1975 and since 1979, the survey was expanded to encompass more of the EBS shelf occupied by pollock. The level of sampling for lengths and ages in the bottom-trawl survey is shown in Table 1.5.

Since 1983 the biomass estimates have been relatively high and showed an increasing trend through 1990 (Table 1.6). Between 1991 and 2002 the bottom trawl survey biomass estimate has ranged from 2.2 to 5.5 million t. The estimate for 2002 is 4.82 million tons, up 16% from the 2001 estimate. In general, the survey indicates a relatively stable stock trend since 1982 with periods of 3-4 years of increases and decreases (Fig. 1.10). This variability is due to the effect of year class variability evident from survey abundance-at-age estimates (Fig. 1.11). One characteristic of year class variability from survey data is that some strong year classes appear in the surveys over several ages (e.g., the 1989 year class) while others appear at older ages (e.g., the 1992 year class). This suggests that the age-specific spatial distribution of pollock available to bottom-trawl gear is variable.

In 2002, pollock catch-rates were higher than normal north of St. Matthew Island and more pollock were found in the middle region of the shelf than usual (Fig. 1.12). This reflects the warmer than average temperatures observed on the shelf this year. Compared with the “average” density of pollock found in the EBS shelf, 2002 had higher concentrations than usual on the shelf and somewhat lower concentrations of pollock at the shelf break.

The survey age composition information provides insights on temporal patterns in length-at-age. In particular, when converted to weights-at-age it appears that in recent years the average size (ages 4-8) is about 90% of the average since 1982. (Fig. 1.13). Since 1982, the pattern in size at age shows a regular periodic trend about every 10 years. This pattern seems to be inversely related (approximately) to pollock abundance and suggests that density dependent processes may be involved.

As in the past few assessments, we conducted an analysis on the total mortality of the 1974-1993 cohorts based solely on NMFS survey data. This simple approach involves regressing the log-abundance of age 6 and older pollock against age by cohort. We selected age 6 because younger pollock are still recruiting to the bottom trawl survey gear. A key assumption of this analysis is that all ages are equally available to the gear. The estimates of total mortality by cohort are difficult to interpret—here we take them as some form of average mortality over the life of the cohort (since we know that harvest rates varied from year to year). The values used in the regression are shown in Fig. 1.14. The estimates of mortality shows somewhat of an increasing trend for these cohorts with a mean total instantaneous value around 0.45 (except for the 1990-1992 cohorts; Fig. 1.15). The low values estimated from some year classes, namely the 1990-1992 cohorts, could be due to the fact that there are fewer age-groups (6, 5, and 4, respectively) in the regressions. Alternatively, it may suggest some net immigration into the survey area or a period of lower natural mortality. In general, these values are consistent with the types of values obtained from within the assessment models for total mortality (though the model values tend to be somewhat higher, averaging about 0.5 for these cohorts).

#### *Studies on the spatial abundance by area*

NMFS groundfish survey data provide insights on the movement and distribution of Bering Sea pollock. Recently, survey CPUE data have been compiled on an age-specific basis. This facilitates comparing catch rates by age over space and time. One application of such analyses is to examine the relative abundance inside and outside of management areas. For example, catch rates inside of the Sea lion conservation area shows the tendency for few young fish and relatively high old-fish catch rates compared to pollock outside of the SCA (Fig. 1.16). This gives some indication of how selectivity/availability of the age-structured population may change under different geographical management practices.

### *Effect of temperature*

Last year we introduced explicit use of bottom temperature data collected during the NMFS summer bottom-trawl surveys. In Ianelli et al. (2001) they showed that temperature affects the distribution of pollock on the shelf and by extension can affect the availability of the stock to the survey. That is, temperature may affect the proportion of the stock that is within or outside of the standard survey area. These patterns were further examined by comparing pollock density with selected on-bottom isotherms (Fig. 1.17). This shows that 2002 was warmer than usual and that, in general, pollock densities are rare at temperatures lower than 0 degrees.

## 1.3.2. Echo-integration trawl (EIT) surveys

Whereas bottom trawl surveys are conducted annually and assess pollock from the bottom to 3 m off bottom, EIT surveys have been conducted approximately triennially since 1979 to estimate pollock in midwater (Traynor and Nelson 1985). However, 7 EIT summer surveys have been conducted since 1991. The details and research results from these EIT surveys have been presented in detail in previous assessments (e.g., Ianelli et al. 2000).

Proportions of pollock biomass estimated east vs. west of 170º W, and inside vs. outside the sea lion conservation area (SCA), are about the same for summer EIT surveys conducted from 1994 to 2002 (Table 1.7). The time series of estimated EIT survey proportions-at-age is presented in Fig. 1.18. The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.8. Since 2000, NMFS has conducted winter EIT surveys on the EBS shelf region in addition to the Bogoslof Island region (Honkalehto et al. 2002). These added areas cover most of the SCA. One purpose of these studies is to assess the variability of pollock concentrated within this zone by season and over different years. Preliminary analyses piecing these data together with the main assessment model have provided some indication that the population tends to aggregate within the SCA in the winter. Unfortunately, the estimated “available” segment of the population (based on age compositions from 1991, 1995, 2000 - 2002 surveys) suggests that a broad range of ages are either within the shelf area but not fully vulnerable to the trawl or echo sign (e.g., the fish could be on the bottom and hence not counted in the echo-integration procedure); or outside of the area. Unfortunately, the relative degree of vulnerability/availability is difficult to quantify. Presumably, younger fish tended to be outside of this region during the winter (since they are commonly found/caught during summer EIT surveys) while older bigger fish may be in the area but close to the bottom (as indicated from bottom trawl surveys). Geographically, the bottom-trawl survey and the EIT survey showed very similar patterns in pollock abundance (Fig. 1.19).

## 1.4. Analytic approach

### 1.4.1. Model structure

The SAM analysis was first introduced in the 1996 SAFE (Ianelli 1996) and was compared with the cohort-analysis method that has been used extensively for pollock in past years. Since the cohort-analyses methods can be thought of as special cases of the SAM analysis (e.g., as shown in Ianelli 1997), we have not continued the use of VPA/cohort algorithms due to their limitations in dealing with many aspects of data in a statistical sense. The statistical age-structured approach has also been documented from analyses performed on simulated data for the Academy of Sciences National Research Council (Ianelli and Fournier 1998). Other changes from last year's analyses include:

- The 2002 EBS bottom trawl survey estimate of population numbers-at-age was included.
- Preliminary estimates of the 2002 EBS EIT survey population numbers-at-age was computed using the 2002 bottom-trawl survey age-length key.

The technical aspects of this model are presented in Section 1.14 and have been presented previously (Ianelli 1996, and Ianelli and Fournier 1998). Briefly, the model structure is developed following Fournier and Archibald's (1982) methods, with a number of similarities to Methot's extension (1990). We implemented the model using automatic differentiation software developed as a set of libraries under the C++ language.

### 1.4.2. Parameters estimated independently

#### *Natural Mortality and maturity at age*

We assumed fixed natural mortality-at-age values based on studies of Wespestad and Terry (1984). These provide estimates of M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively. These values have been used since 1982 in catch-age models and forecasts and appear to approximate the true rate of natural mortality for pollock. Recent studies on Gulf of Alaska pollock indicate that natural mortality may be considerably higher when predators are taken explicitly into account (Livingston and Method 1998, Hollowed et al. 2000, Bailey 2001). This may also hold for the EBS region, however, the abundance of pollock is proportionately much higher than all other fish species compared to the Gulf of Alaska. This may explain why cannibalism is much more common in the EBS than in the Gulf. Note that to some degree, the role of cannibalism is modeled through the implementation of a Ricker (1975) stock-recruitment curve. This relationship can curve downwards where at higher stock sizes lower average recruitment levels are expected.

Livingston and Methot (1998) and Hollowed et al. (2000) investigated sources of natural mortality for pollock. Their results concluded that when pollock consumption by predators (e.g., Steller sea lions, Pacific cod) are accounted for, "natural mortality" was considerably higher than the values used here. Specifying a conservative (lower) natural mortality rate is more precautionary (Clark 1999).

Maturity at age was assumed the same as that given in Wespestad (1995) which dates back to Smith (1981). This was shown to be consistent with maturity observed in winter surveys in recent years. Pollock reproductive studies are continuing and will be an active study area with sample collections planned for future winter surveys and fishing operations. These values are given here together with the baseline assumption of natural mortality-at-age:

| Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| M | 0.900 | 0.450 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | |
| Prop. Mature | 0.000 | 0.008 | 0.290 | 0.642 | 0.842 | 0.902 | 0.948 | |
| **Age** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
| M | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 |
| Prop. Mature | 0.964 | 0.970 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

### *Length and Weight at Age*

Length, weight, and age data have been collected extensively for pollock. Samples of length-age and weight-length data within each stratum indicate growth differences by sex, area, and year class. General patterns have been that pollock in the northwest area are slightly smaller at age than in the southeast. Since our estimates of harvests-at-age are stratified by area (and season), these differences are taken into account before analyses within the model. For the fishery, we use year (when available) and age-specific estimates of average weights-at-age as computed from the fishery age and length sampling programs. These values are shown in Table 1.9 and are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight). Since we do not assume a fishery catch-effort relationship explicitly, the fishing mortality rates depend largely on the total annual harvests by weight. For the bottom-trawl and EIT surveys, we tune the model to estimates of total numbers of fish.

### 1.4.3. Parameters estimated conditionally

For the reference model presented here, 580 parameters were estimated. These include vectors describing recruitment variability in the first year (as ages 2-15 in 1964) and the recruitment deviations (at age 1) from 1964-2002. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (2003-2007). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1964 (that comprises the initial age composition in that year) to have a mean value different from subsequent years. Thus, 62 parameters comprise initial age composition, subsequent recruitment values and stock-recruitment parameters.

Fishing mortality is parameterized to be semi-separable. That is, there is a year component and an age (selectivity) component. The age component is allowed to vary over time with changes allowed every three years. The age component is constrained such that its mean value will be equal to one, this means that it will not be confounded with the time component (see Section 1.14, Model details). In addition, we assume that the age-component parameters are constant for the last 4 age groups (ages 12-15). Therefore, the time component of fishing mortality numbers 40 parameters (estimable since we place low variance on the likelihood component on the total catch biomass) and the added age-time component of variability results in a 11x13 matrix of 143 parameters. This brings the total fishing mortality parameters to 183. Please note however, that in standard cohort analyses such as that of Pope (1972) the number of parameters for a similarly dimensioned problem would be 39x15 or 585 fishing mortality parameters. Of course in a VPA, these parameters are not estimated statistically, rather implicitly using an algorithm that assumes no errors in the total catch-at-age.

For the bottom trawl survey, a similar parameterization for the selectivity-at-age estimates includes an overall catchability coefficient, age and year specific deviations in the average availability-at-age which totals 66 parameters for these data (for the logistic time-varying selectivity curves). For the EIT survey, which began in 1979, there are 264 parameters describing age-time specific availability. Estimates for changes in EIT selectivity sometimes occur for years when the survey was not conducted. This increases the number of parameters we estimate, but avoids problems associated with surveys occurring on irregularly spaced intervals. The idea of estimating these changes is to allow some continuity in unaccounted-for variability of fish available to our survey gear. That is, we expect things to change in this regard but our null hypothesis is that the survey operation is constant with respect to relative changes in age class availability.

As last year, we evaluate the effect of temperature ($T_t$) on the survey catchability in year *t* as:

$$q_t = \mu_q + \beta_q T_t$$

where $\mu_q$ is the mean catchability and $\beta_q$ represents the slope parameter. The time series of temperature (Fig. 1.20) is used in Model 4 (which, for the model was normalized to have a mean value of zero).

For all other models, the catchability coefficient for the bottom-trawl survey is estimated in the same manner as is done for the other two indices (early CPUE data and the EIT survey).

Finally, 2 additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$ and $F_{35\%}$ harvest rates. These rates satisfy the constraint that given selectivity-at-age vector (we used the mean selectivities based on model configuration), proportion-mature-at-age, natural mortality rate, and weight at age, there are unique values that correspond to the fishing mortality rates.

The likelihood components can thus be partitioned into the following groups:

- Total catch biomass (Log normal, $\sigma$=0.05)
- Bottom trawl survey variances (annual estimates of standard error, as represented in Fig. 1.10) and an assumed variance for the EIT survey abundance index, (i.e., Log normal, $\sigma$=0.2)
- Fishery and survey proportions-at-age estimates (Robust quasi-multinomial with effective sample sizes presented in Table 1.10). These values were selected based on comparisons of catch-at-age variance estimates obtained from the fishery stratified sampling scheme (Kimura 1989) with values obtained in earlier fits to the stock assessment model (Ianelli 1996, Table A1, Annex B).
- Selectivity constraints (penalties on age-age variability, time changes, and decreasing (with age) patterns)
- Stock-recruitment penalties (penalties involved with fitting a stochastic stock-recruitment relationship within the integrated model).

## 1.5. Model evaluation

To examine model assumptions and data sensitivities, we evaluated several dozen different model configurations. For clarity, we present a limited number of these results. Some of these are in response to specific requests by the NPFMC family and others are intended to illustrate some properties of model behavior relative to the extensive surveys and fishery observations conducted by the AFSC for walleye pollock.

A list of the models presented includes:

**Model 1** **Reference model,** future selectivity based on most recent (3-year) estimate (short-term selectivity estimate). This was the model configuration selected by the Council for ABC recommendations in last year’s assessment.

**Model 2** As reference model but with bottom-trawl survey selectivities modeled as coefficients varying over time (and possibly decreasing with age).

**Model 3** As reference model but with fishery selectivity allowed to change more frequently over time.

**Model 4** As reference model but with bottom-trawl survey catchability including an environmental covariate (bottom temperature).

**Model 5** As reference model, but with bottom-trawl survey catchability fixed at 1.0.

**Model 6** As Model 5 but estimating natural mortality.

**Model 7** As Reference Model, but disregarding the survey information.

These models can be summarized as follows:

| Model | Description |
|---|---|
| 1 | Reference model |
| 2 | Dome-shaped survey selectivity allowed |
| 3 | Fishery selectivity allowed to vary more frequently |
| 4 | Bottom temperature a covariate with survey catchability |
| 5 | Bottom-trawl survey catchability fixed at 1.0. |
| 6 | Estimate natural mortality |
| 7 | Disregard all survey data |

Our reference model can be characterized as one that includes a moderate number of stochastic processes. These are principally changes in age-specific availability over time for survey and fishery gears and recruitment variability. As specified, these processes involve a large number of parameters but capture a reasonable amount of the overall uncertainty.

Comparing this result with that used in the 2000 assessment (e.g., Model 2) gives an improved goodness of fit (i.e., a lower –ln(likelihood) function; Table 1.11). Also, the stock condition estimates from Model 1 are slightly less optimistic compared to Model 2 (Table 1.12). Last year we developed a new treatment of age-specific selectivity for the bottom-trawl survey (since asymptotic selectivity seems most appropriate for this gear type). This is now our preferred form since pollock appear to reside more on the bottom as they age.

As with last year, the stock-recruitment curve fitting for the Reference model (Model 1) is using only the period from 1978-2002. Also as with last year we ran models with many stock-recruitment alternatives (including: Beverton-Holt, constant recruitment, different assumptions about specified priors on steepness, length of time series used for estimating stock-recruitment relationship etc.). Several of these alternative model specifications were presented in Ianelli et al. (2000) and all gave more optimistic scenarios than the Reference Model presented here.

In 2000, the Council's SSC requested that we examine alternatives where selectivity was allowed to vary more frequently over time. We first examined implementing a time-varying 4-parameter logistic function (with several alternative parameterizations). Our experience here was that the estimation became unstable. The reason we think this occurred was due to the fact that as the parameters for the selectivity function approached an ascending-asymptotic form, the parameters describing the descending limb of the selectivity function no-longer had correct derivatives. Since the 4-parameter logistic is a non-differentiable function problems can arise when derivatives are automatically computed (regardless if they are estimated by finite-difference methods). As a fall-back, we allowed the coefficients to vary every two years as in Model 3 and also in every year (though we chose not to present these results since they were very similar). Results from this configuration improved the fit to the data while other stock indicators were very similar to the reference case. Models 1 and 3 represent the uncertainty in the fishery age-specific selection process equally well.

Since there is some indication that the geographical distribution of pollock as observed by bottom-trawl survey gear shifts depending on temperature, we introduced mean bottom temperature as having an effect on survey catchability (Model 4). Results suggest that there is a slight negative relationship between bottom temperatures and survey catchability (slope -0.103, with standard error 0.125). The significance of this fit is low given this standard error, and the overall fit is only slightly better (the -lnL improves by 0.32 units compared to Model 1; Table 1.11). It appears that survey catchability tends to be slightly lower at warmer temperatures and slightly higher at colder temperatures (Fig. 1.21). In other words, in cold years pollock appear to be more available to the survey gear than in warm years. For contrast, in Model 5 we constrained survey catchability to be exactly equal to one. This resulted in a worse fit to the data and a much higher biomass estimate.

Obtaining model estimates of survey catchability that are greater than 1.0 may seem counterintuitive, given that we expect the bottom-trawl gear to be missing pollock that are up in the water column and outside of the survey area. We note that there is a significant age-component to this catchability and that the estimates are likely an artifact of model mis-specification rather than due to the effects of "herding" or other survey mechanism. For example, factoring the age-effect (selectivity) of the survey gear and considering the average biomass of pollock age 5 and older, the survey catchability is slightly less than 1.0. Considering age 3 and older pollock biomass, the average catchability by the survey is about 0.70. This effect is because young pollock are less available to bottom-trawl survey gear.

In Model 6 we evaluated the ability of our model to estimate natural mortality (with survey catchability fixed at a value of 1.0). The parameterization was specified for age-3 and older as $Me^{\rho}$ where the estimate was (from *M=0.3*): $\hat{\rho}$=0.061 with a standard error of 0.086 (and $Me^{\rho}$=0.319). This suggests that given the current model specification, alternative estimates of natural mortality are similar. Note that last year this model resulted in a higher estimate of natural mortality (0.33). Presumably additional data (consistent with the catch-curve analyses presented above) suggests a lower value and possibly a time trend.

Finally, in Model 7 we examined the influence of our survey data on assessment model results. Disregarding both survey indices and age composition data sets (the data were still physically included in the model, but were downweighted in the –ln(likelihood) function to 1/100th of their original emphasis. This model yielded results surprisingly similar to Model 1, but with greater uncertainty.

In the past few years we've included an analysis using an ocean current circulation model to aid in the estimation of year-class strengths for forecasting. This model was not updated this year. However, its implementation had relatively little impact on values critical for harvest management regulations. The environmental effect did not appear to shift or influence the underlying stock-recruitment relationship that was estimated (although it did help explain part of the inter-annual variability).

Based on the examinations of the alternative models presented here (and also over those that were run but not presented) we feel that our Model 1 is appropriate and encompasses a wide range of uncertainties about the stock status.

Questions often arise about how biomass estimates from different surveys relate to model results since they are typically quite different. For example, the "total age-3+ biomass" estimates for 2001 are over 11 million tons compared to the bottom-trawl survey biomass estimate of slightly more than 4.1 million tons. Such a difference can be attributed to three main factors: **weight** (averaged by age), **time** (within a year), and **selectivity/availability**. Last year we presented the effects of these factors in detail. The same interpretation issues apply in the current assessment—namely that "biomass estimates" depend on the ages considered (and the catchability implications from surveys), the time of year, and the average weight estimates.

## 1.6. Results

Several key results have been summarized in Tables 1.12 & 1.13. The difference in the current and projected age structure for Model 1 relative to the last year's assessment (2001) is shown in Fig. 1.22. This figure shows that the absolute numbers at age are estimated to be somewhat higher in the current assessment. The 1992 year class is estimated to be slightly higher than in the past, presumably due to the predominance of that year class in the recent EBS bottom-trawl surveys and in the fishery (e.g., Fig. 1.27 below). The 1996 year class is still estimated to be quite strong but is slightly lower than last year's estimate. This is due to the survey estimates being lower than expected for this age class. Conversely, the 1995 year class continues (slightly) to have grown in strength based on the bottom-trawl survey data; e.g., Fig. 1.11).

The estimated Model 1 selectivity pattern changes over time to become slightly more dome-shaped during the 1990s (Fig. 1.23). This may have coincided with the move to pelagic-only trawl gear as larger (older) fish tend to be more bottom-oriented. Model 1 fits the fishery age-composition data quite well and strong year classes are clearly evident (Fig. 1.24). The fit to the early Japanese fishery CPUE data (Low and Ikeda, 1980) is consistent with the populations trends for this period (Fig. 1.25).

We specified that selectivity could vary slightly over time for both surveys. This was done to account for potential changes in fish distribution. For example, it seems reasonable to assume that the presence of 1-year-olds available to the bottom-trawl gear on the shelf might be variable, even when the abundance is the same (Fig. 1.26). The bottom trawl survey age composition data are somewhat inconsistent in 2000 and 2001. The abundance of the 1995 year class has apparently increased while the proportion of the 1996 year class in these years was lower than expected (Fig. 1.27). This trend has continued with the addition of this year's data. Since the 1996 year class is so important to the fishery in the near-term, this development requires close attention (even though the 1996 year class has consistently appeared strong in the EIT survey (see below) and the fishery). We also point out that the 1992 year class was not well observed by the bottom trawl survey as age 3, 4, and to some extent, 5-year old pollock.

The Model 1 fit and estimated selectivity for the EIT survey data show a dramatic change in selectivity pattern over time (Fig. 1.28). This may be due in part to changes in pollock distribution (as the overall densities changed and also to the fact that large numbers of 1 and 2-year old fish were apparent in the survey that year. Also, the number of hauls sampled has generally increased over time—presumably this trend affects the overall estimate of the age composition of pollock available to the survey. These patterns are also illustrated in the model fit to the EIT survey age composition data (Fig. 1.29). The proportions at age observed in the survey are generally consistent with what appeared later in the bottom-trawl survey and fishery. Estimated numbers-at-age for Model 1 are presented in Table 1.14 and estimated catch-at-age presented in Table 1.15.

Uncertainty computations are a central part of the analyses presented in this assessment. In the past year, development of Bayesian integration methods has continued. Often with highly non-linear models, the multidimensional shape of the posterior distribution can be highly curved and present problems when expressing approximations to marginal distributions (e.g., as we do here via the Delta-method propagation-of-errors to obtain variance estimates for management quantities of interest). To explore this property, we computed the joint distribution based on 1 million Monte-Carlo Markov Chain simulations drawn from the posterior distribution. The chain was thinned to reduce potential serial correlation to 5,000 parameter "draws" from the posterior distribution. Selected model parameters (Model 1) are plotted pair-wise to provide some indication of the shape of the posterior distribution. In general, the model given the available data appears to be quite well behaved (clusters of parameters do not appear to follow strange curved or skewed tear-drop shapes; Fig. 1.30). In terms of policy evaluation, we projected the model forward (for each "sample" from the posterior) with a fixed catch of 1.3 million tons. The probability that the current stock size is below the (uncertain) $B_{40\%}$ level is quite low. However, by 2004, the expectation is that the stock size will be well above the $B_{40\%}$ stock size level (with about 30% probability), then increase (with considerable uncertainty) to well above this level by 2007 (Fig. 1.31).

### 1.6.1. Abundance and exploitation trends

The eastern Bering Sea bottom trawl survey estimates exhibited an increasing trend during the 1980s, were relatively stable from 1991 to 1995, and decreased sharply in 1996 but rose slightly in 1997 and then substantially in 1999 and 2000. This may be due, in part, to age-related distribution changes within the pollock population. Results from combined bottom trawl and EIT surveys, which more fully sample the population, have shown that older pollock are more vulnerable to bottom trawls than younger pollock (e.g., Figs. 1.26 and 1.27).

Current "exploitable" biomass estimates (ages 3 and older) derived from the statistical catch-age model suggest that the abundance of eastern Bering Sea pollock remained at a fairly high level from 1982-88, with estimates ranging from 10 to 11.5 million t. Peak biomass occurred in 1985 and declined to about 5 million t by 1991. Since then, the age 3 and older biomass has increased, and recently been variable around 10 million tons[1].

Historically, biomass levels have increased from 1979 to the mid-1980's due to the strong 1978 and relatively strong 1982 and 1984 year classes recruiting to the fishable population (Table 1.16, Fig. 1.32). From 1985-86 to 1991 the fishable stock declined as these above average year classes decreased in abundance with age and were replaced by weaker year classes. In 1992 an upturn in abundance began with the recruitment of a strong 1989 year class and peaked around 1995. An increase in abundance is expected in future years as apparently above average 1996 year class recruits to the exploitable population.

Since 1999 the mid-year age 3+ model estimate of EBS pollock biomass has dropped by 18% as the 1996 year class has aged through the stock.

Retrospectively, compared with last year's assessment the recent estimates of age 3+ pollock biomass are somewhat lower in the current assessment during the 1980s and higher in recent years (Table 1.16). Again, this may be attributed to the increasing trends from both the EIT and bottom trawl survey estimates for 1999. Overall, compared with seven past assessments, the retrospective pattern shows a steady increase in estimates of stock size during the late 1990s (Fig. 1.33).

The abundance and exploitation pattern estimated from Model 1 shows that the spawning exploitation rate (SER, defined as the percent removal of spawning-aged females in any given year) has averaged about 18% in the past 10 years (Fig. 1.34). This compares to an overall average SER of 22.5% (1964 – 2000). The observed variation in pollock abundance is primarily due to natural variation in the survival of individual year classes. These values of SER are relatively low compared to the estimates at the MSY level (~30%).

### 1.6.2. Recruitment

Recruitment of pollock is highly variable and difficult to predict. It is becoming clear that there is a great deal of variation in the distribution of pre-recruit pollock, both in depth and geographic area. To some extent, our approach takes this into account since age 1 fish are included in our model and data from both the EIT and bottom trawl survey are used. In earlier assessments (prior to 1998), the primary measure of pollock recruitment has been the relative abundance of age 1 pollock (or pollock smaller than 20 cm when age data are unavailable) in the annual eastern Bering Sea bottom-trawl survey. Also, bottom-trawl

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[1] Please refer to Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

survey estimates of age 1 recruitment, when regressed against age 3 pollock estimates from catch-age models, indicate a linear relationship. This had been used to project age 3 numbers in population forecasts. Our method does not require external regressions since the necessary accounting is done explicitly, within a standard age-structured model. The key advantage in our approach is that the observation and process errors are maintained and their effect can be evaluated.

It appears that the annual bottom trawl survey does not fully cover the distribution of age 1 pollock. This is especially evident for the 1989 year class that the survey found to be slightly below average, but upon recruitment to the fishery, was a very strong year class. It appears that a significant amount of this year class was distributed in the Russian EEZ—beyond the standard survey area—or unavailable to bottom trawl gear (perhaps in mid-water). In 1996, Russian scientists reported the 1995 year class to be strong, but it appeared to be below average in the U.S. survey. However, in the 1997 EIT survey the 1995 year class was abundant adjacent to the Russian EEZ.

The coefficient of variation or “CV” (reflecting uncertainty) on the strength of the 1996 year class is about 15% for Model 1 (down from 25% last year). As this year class ages, the magnitude of the incoming recruitment will be vital to future stock conditions. Currently, the 1999 year class appears to be slightly above average while the 2000 year class appears about average (both with wide confidence margins; Fig. 1.35). As more survey observations on these year classes occur, the precision of these estimates are expected to increase.

## 1.7. Projections and harvest alternatives

### 1.7.1. Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines “overfishing level” (OFL), the fishing mortality rate used to set OFL ($F_{OFL}$), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC ($F_{ABC}$) may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available. However, the extent of their reliability is questionable. We therefore present both reference points for pollock in the BSAI to retain the option for classification in either Tier 1 or Tier 3 of Amendment 56. These Tiers require reference point estimates for biomass level determinations. For our analyses, we selected the following values from Model 1 results computed based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 6,886 thousand t female spawning biomass[2]

$B_{40\%}$ = **2,691** thousand t female spawning biomass

$B_{35\%}$ = **2,410** thousand t female spawning biomass

$B_{msy}$ = **2,293** thousand t female spawning biomass

[2] Note that another theoretical “unfished spawning biomass level” (based on stock-recruitment relationship $\tilde{B}_0$) is somewhat lower (5,868 t).

### 1.7.2. Specification of OFL and Maximum Permissible ABC

For Model 1, the year 2003 spawning biomass is estimated to be 3,115 thousand tons (at the time of spawning, assuming the stock is fished at $F_{msy}$). This is well above the $B_{msy}$ value of 2,293. Under Amendment 56, Tier 1a, the harmonic mean value is considered a risk-averse policy provided reliable estimates of $F_{msy}$ and its pdf are available. The harmonic mean value for $F_{msy}$ computations is somewhat different from the procedure outlined in Tier 1 of Amendment 56. Here the harmonic mean is computed from the estimated pdf for the year 2003 yield under $F_{msy}$ rather than first finding the harmonic mean of $F_{msy}$ and applying its value to the maximum likelihood estimate for the year 2003 stock size. The method we use results in somewhat lower ABC values since uncertainty in both the $F_{msy}$ value and future stock size are both considered.

Corresponding values under Tier 3 are 3,328 thousand tons for year 2003 spawning values (under $F_{40\%}$ policy). This is well above the $B_{35\%}$ value of 2,410 . The OFL's and maximum permissible ABC values by both methods are thus:

| | OFL | Max ABC |
|---|---|---|
| **Tier 1a** | **3,532 thousand t** | **2,327 thousand t** |
| **Tier 3a** | **2,869 thousand t** | **2,322 thousand t** |

### 1.7.3. ABC Recommendation

Currently, the biomass of eastern Bering Sea pollock appears to be quite high and decreasing. The total begin-year age-3+ biomass in 2003 is projected to be about 10.8 million t the estimated female spawning biomass projected to the time of spawning in the year 2002 is about **3,328** thousand tons, well above of the $B_{40\%}$ level of **2,610** thousand tons and well above the $B_{35\%}$ and the value estimated for $B_{msy}$ (**2,410** and **2,293** respectively; Fig. 1.36).

For the year 2002, maximum permissible ABC alternatives based on the $F_{40\%}$ and harmonic-mean $F_{msy}$ are 2,322 and 2,327 thousand tons, respectively for the reference model ($F_{msy}$ harvests based on the harmonic mean value) as shown in Table 1.13 for Model 1. However, subsequent recruitment has been below average (though is highly uncertain). Hence, short-term projections (shown below) predict that the spawning stock is likely to drop below the $B_{40\%}$ and $B_{msy}$ levels. There is nothing intrinsically wrong with having the population drop below the optimal level (since under perfect management, it is expected to be below the target exactly half of the time). However, choosing a harvest level that reduces this likelihood could 1) provide stability to the fishery; 2) provide added conservation given the current Steller sea lion population declines; and 3) provide added conservation due to unknown stock removals in Russian waters. Therefore it seems prudent to recommend a harvest level lower than the maximum permissible values. As an example, under constant catch scenarios of 1.4 and 1.3 million tons, the stock is expected to remain well above the $B_{40\%}$ level (Fig. 1.37).

### 1.7.4. Standard Harvest Scenarios and Projection Methodology

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2002 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow (A "*max* $F_{ABC}$" refers to the maximum permissible value of $F_{ABC}$ under Amendment 56):

*Scenario 1*: In all future years, *F* is set equal to *max* $F_{ABC}$. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

*Scenario 2*: In all future years, *F* is set equal to a constant fraction of *max* $F_{ABC}$, where this fraction is equal to the ratio of the $F_{ABC}$ value for 2003 recommended in the assessment to the *max* $F_{ABC}$ for 2003. (Rationale: When $F_{ABC}$ is set at a value below *max* $F_{ABC}$, it is often set at the value recommended in the stock assessment.)

*Scenario 3*: In all future years, *F* is set equal to 50% of max $F_{ABC}$. (Rationale: This scenario provides a likely lower bound on $F_{ABC}$ that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

*Scenario 4*: In all future years, *F* is set equal to the 1998-2002 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of $F_{TAC}$ than $F_{ABC}$.)

*Scenario 5*: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

*Scenario 6*: In all future years, F is set equal to FOFL. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2003 or 2) above ½ of its MSY level in 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

*Scenario 7*: In 2003 and 2004, *F* is set equal to *max* $F_{ABC}$, and in all subsequent years, *F* is set equal to $F_{OFL}$. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not approaching an overfished condition.)

### 1.7.5. Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the max $F_{ABC}$ value and use $F_{35\%}$ as a proxy for $F_{msy}$. Scenarios 1 through 7 were projected 14 years from 2002 (Table 1.17). Under Scenario 1, the expected spawning biomass will decrease to slightly below $B_{35\%}$ then increase to above $B_{40\%}$ by the year 2007 (Fig. 1.36). Under this scenario, the yields are expected to vary between 1.0 – 1.8 million tons. If the highly conservative catch levels (estimated from the last 5 years) are to continue, then the stock is not projected to drop below $B_{40\%}$ at any time in the future (Fig. 1.38).

Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2002:

a) If spawning biomass for 2002 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

b) If spawning biomass for 2002 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2002 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Table 1.17). If the mean spawning biomass for 2012 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

a) If the mean spawning biomass for 2004 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2004 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2004 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2014. If the mean spawning biomass for 2014 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2002, nor is it expected to be approaching an overfished condition based on Scenario 7.

## 1.8. Other considerations

### 1.8.1. Ecosystem considerations

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch (via multi-species analyses of technical interactions);
- Controlling the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock in the EBS, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single-species harvest approach. The prevention of overfishing is clearly set out as a main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the NMFS observer program and managed on that basis. Discarding rates have been greatly reduced in this fishery and multi-species interactions is an ongoing research project within NMFS with extensive food-habit studies and simulation analyses to evaluate a number "what if" scenarios with multi-species interactions.

In general, the climatic conditions that may affect the Bering Sea ecosystem have apparently undergone a change since the late 1990s. After spending most of the 1990s in positive mode the Pacific Decadal Oscillation (PDO) shifted to negative in 1998/99. This coincides with cooler-than-average northeastern Pacific surface temperatures and warmer-than-average central Pacific surface temperatures. This negative PDO has continued into 2001 and 2002. The implications are that the eastern Bering Sea is getting warmer and could probably stay warmer for a while. Coincidentally, the OSCURS model runs have shown a tendency for April-May-June surface currents in the eastern Bering Sea to resume stronger on-shelf drift in 3 of the last 5 years (1998, 1999, 2002) after a hiatus since 1991 (Jim Ingraham, pers. comm.). This may indicate favorable conditions for pollock survival during these years.

A recent analysis comparing the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models was published this year (Aydin et al., 2002). This study shows that the production in these two systems is quite different. On a per-unit-area measure, the western Bering Sea has higher productivity than the EBS. Also, the pathways of this productivity are different with much of the energy flowing through epifaunal species (e.g., sea urchins and brittlestars) in the WBS whereas for the EBS, crab and flatfish species play a similar role. In both regions, the keystone species are pollock and Pacific cod. Based on the evaluation the food web using a mass-balance equation, Aydin et al. (2002) found that the EBS ecosystem was relatively mature due to the large number of interconnections.

Another way of evaluating ecosystem considerations is to look at how the **ecosystem affects the EBS pollock stock** and at how the **EBS pollock fishery affects the ecosystem.** A brief summary of these two perspectives is given in Table 1.18. Unlike the food-web models discussed above, examining predators and prey in isolation may overly simplify relationships. This table serves to highlight the main connections and the status of our understanding or lack thereof.

### 1.8.2. Fishing fleet dynamics

It has become common knowledge that several (most) vessels fishing for pollock have made gear modifications designed to reduce the take of under-sized fish. This may change the effective selectivity of the gear in a predictable way. While our approach allows for changes in selectivity, further analyses on this effect may be warranted. Other substantial changes are occurring with the implementation of the RPA's and the American Fisheries Act (AFA). These have reduced the "race for fish" that was common in years before 1999. The impact of the AFA reduces bycatch and improves recovery percentages. In addition, the ability to avoid small fish will be enhanced since the fishery occurs over longer periods with lower daily harvest rates.

## 1.9. Summary

Summary results are given in Table 1.19.

## 1.10. Acknowledgements

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## 1.12. Tables

Table 1.1 Catch from the eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979-2002. (2002 values set equal to TAC). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W.

| | Eastern Bering Sea | | | Aleutians | Donut Hole | Bogoslof I. |
|---|---|---|---|---|---|---|
| Year | Southeast | Northwest | Total | | | |
| 1979 | 368,848 | 566,866 | 935,714 | 9,504 | | |
| 1980 | 437,253 | 521,027 | 958,280 | 58,156 | | |
| 1981 | 714,584 | 258,918 | 973,502 | 55,516 | | |
| 1982 | 713,912 | 242,052 | 955,964 | 57,978 | | |
| 1983 | 687,504 | 293,946 | 981,450 | 59,026 | | |
| 1984 | 442,733 | 649,322 | 1,092,055 | 81,834 | 181,200 | |
| 1985 | 604,465 | 535,211 | 1,139,676 | 58,730 | 363,400 | |
| 1986 | 594,997 | 546,996 | 1,141,993 | 46,641 | 1,039,800 | |
| 1987 | 529,461 | 329,955 | 859,416 | 28,720 | 1,326,300 | 377,436 |
| 1988 | 931,812 | 296,909 | 1,228,721 | 30,000 | 1,395,900 | 87,813 |
| 1989 | 904,201 | 325,399 | 1,229,600 | 15,531 | 1,447,600 | 36,073 |
| 1990 | 640,511 | 814,682 | 1,455,193 | 79,025 | 917,400 | 151,672 |
| 1991 | 712,206 | 505,095 | 1,217,301 | 78,649 | 293,400 | 264,760 |
| 1992 | 663,457 | 500,983 | 1,164,440 | 48,745 | 10,000 | 160 |
| 1993 | 1,095,314 | 231,287 | 1,326,601 | 57,132 | 1,957 | 886 |
| 1994 | 1,183,360 | 180,098 | 1,363,458 | 58,637 | NA | 566 |
| 1995 | 1,170,828 | 91,939 | 1,262,766 | 64,429 | trace | 264 |
| 1996 | 1,086,840 | 105,938 | 1,192,778 | 29,062 | trace | 387 |
| 1997 | 820,050 | 304,543 | 1,124,593 | 25,940 | trace | 168 |
| 1998 | 965,766 | 135,399 | 1,101,165 | 23,822 | trace | 136 |
| 1999 | 814,622 | 177,378 | 988,674 | 965 | trace | 29 |
| 2000 | 839,175 | 293,532 | 1,132,707 | 1,244 | trace | 28 |
| 2001 | 961,975 | 425,219 | 1,387,194 | 824 | trace | 258 |
| 2002 | NA | NA | 1,485,000 | 1,040 | NA | NA |

1979-1989 data are from Pacfin.
1990-2001 data are from NMFS Alaska Regional Office, includes discards.
2002 EBS catch assuming full TAC will be taken; for Aleutians catch data as of Oct 19, 2002

Table 1.2. Estimated retained, discarded, and percent discarded of total catch in the Aleutians, Northwest and Southeastern Bering Sea, 1990-2001. Source: NMFS Blend database.

| **Area** | **Year** | **Catch Retained** | **Discard** | **Total** | **Discard Percentage** |
|---|---|---|---|---|---|
| Southeast (51) | | 582,660 | 57,851 | 640,511 | |
| Northwest (52) | | 764,369 | 50,313 | 814,682 | |
| Aleutians | | 69,682 | 9,343 | 79,025 | |
| Total | **1990** | 1,416,711 | 117,507 | 1,534,218 | 7.7% |
| Southeast (51) | | 614,889 | 97,317 | 712,206 | |
| Northwest (52) | | 458,610 | 46,485 | 505,095 | |
| Aleutians | | 73,608 | 5,041 | 78,649 | |
| Bogoslof | | 245,467 | 19,293 | 264,760 | |
| Total | **1991** | 1,318,966 | 163,095 | 1,482,061 | 11.0% |
| Southeast (51) | | 600,861 | 62,596 | 663,457 | |
| Northwest (52) | | 445,811 | 55,172 | 500,983 | |
| Aleutians | | 45,246 | 3,498 | 48,745 | |
| Total | **1992** | 1,091,919 | 121,266 | 1,213,185 | 10.0% |
| Southeast (51) | | 1,011,020 | 84,294 | 1,095,314 | |
| Northwest (52) | | 205,495 | 25,792 | 231,287 | |
| Aleutians | | 55,399 | 1,733 | 57,132 | |
| Total | **1993** | 1,271,914 | 111819 | 1,383,732 | 8.1% |
| Southeast (51) | | 1,091,547 | 91,813 | 1,183,360 | |
| Northwest (52) | | 164,020 | 16,078 | 180,098 | |
| Aleutians | | 57,325 | 1,311 | 58,637 | |
| Total | **1994** | 1,312,892 | 109,202 | 1,422,094 | 7.7% |
| Southeast (51) | | 1,083,381 | 87,447 | 1,183,360 | |
| Northwest (52) | | 82,226 | 9,713 | 91,939 | |
| Aleutians | | 63,047 | 1,382 | 64,429 | |
| Total | **1995** | 1,228,654 | 98,542 | 1,339,728 | 7.4% |
| Southeast (51) | | 1,015,473 | 71,367 | 1,086,840 | |
| Northwest (52) | | 101,100 | 4,838 | 105,938 | |
| Aleutians | | 28,067 | 994 | 29,062 | |
| Total | **1996** | 1,145,133 | 77,206 | 1,222,339 | 6.3% |
| Southeast (51) | | 749,007 | 71,043 | 820,050 | |
| Northwest (52) | | 281,986 | 22,557 | 304,543 | |
| Aleutians | | 25,323 | 617 | 25,940 | |
| Total | **1997** | 1,056,316 | 94,217 | 1,150,533 | 8.2% |
| Southeast (51) | | 950,631 | 15,135 | 965,767 | |
| Northwest (52) | | 133,818 | 1,581 | 135,399 | |
| Aleutians | | 23,657 | 164 | 23,822 | |
| Total | **1998** | 1,108,106 | 16,881 | 1,124,987 | 1.5% |
| Southeast (51) | | 756,047 | 27,100 | 783,148 | |
| Northwest (52) | | 204,785 | 1,912 | 206,697 | |
| Aleutians | | 529 | 480 | 1,010 | |
| Total | **1999** | 961,362 | 29,492 | 990,855 | 3.0% |
| Southeast (51) | | 819,497 | 19,677 | 839,175 | |
| Northwest (52) | | 291,590 | 1,941 | 293,532 | |
| Aleutians | | 455 | 790 | 1,244 | |
| Total | **2000** | 1,111,543 | 22,408 | 1,133,951 | 2.0% |
| Southeast (Area 51) | | 947,101 | 14,873 | 961,975 | |
| Northwest (Area 52) | | 422,769 | 2,450 | 425,219 | |
| Aleutians | | 445 | 380 | 824 | |

| | | | | | |
|---|---|---|---|---|---|
| Total | **2001** | 1,370,315 | 17,703 | 1,388,018 | 1.3% |

Table 1.3. Eastern Bering Sea walleye pollock observed catch at age in numbers (millions), 1979-2001.

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1979** | 101.4 | 543.2 | 720.0 | 420.2 | 392.6 | 215.5 | 56.3 | 25.7 | 35.9 | 27.5 | 17.6 | 7.9 | 3.0 | 0.5 | 2,567.3 |
| **1980** | 9.8 | 462.4 | 823.3 | 443.5 | 252.2 | 211.0 | 83.7 | 37.6 | 21.8 | 23.9 | 25.5 | 15.9 | 7.7 | 2.5 | 2,420.7 |
| **1981** | 0.6 | 72.2 | 1012.9 | 638.0 | 227.0 | 102.9 | 51.7 | 29.6 | 16.1 | 9.4 | 7.5 | 4.6 | 1.5 | 0.6 | 2,174.6 |
| **1982** | 4.8 | 25.3 | 161.4 | 1172.4 | 422.4 | 103.7 | 36.0 | 36.0 | 21.5 | 9.1 | 5.4 | 3.2 | 1.9 | 0.7 | 2,003.7 |
| **1983** | 5.1 | 118.6 | 157.8 | 313.0 | 817.0 | 218.3 | 41.4 | 24.7 | 19.8 | 11.1 | 7.6 | 4.9 | 3.5 | 1.7 | 1,744.5 |
| **1984** | 2.1 | 45.8 | 88.6 | 430.8 | 491.9 | 654.3 | 133.9 | 35.6 | 25.1 | 15.7 | 7.1 | 2.5 | 2.9 | 1.7 | 1,938.0 |
| **1985** | 2.7 | 55.3 | 382.2 | 122.1 | 366.7 | 322.3 | 444.3 | 112.8 | 36.7 | 25.9 | 24.9 | 10.7 | 9.4 | 4.0 | 1,919.9 |
| **1986** | 3.1 | 86.0 | 92.3 | 748.5 | 214.1 | 378.1 | 221.9 | 214.2 | 59.7 | 15.2 | 3.3 | 2.6 | 0.3 | 1.2 | 2,040.4 |
| **1987** | 0.0 | 19.9 | 112.2 | 78.0 | 415.8 | 139.6 | 123.2 | 91.2 | 248.6 | 54.4 | 38.9 | 21.6 | 29.1 | 6.1 | 1,378.5 |
| **1988** | 0.0 | 10.7 | 455.2 | 422.8 | 252.8 | 545.9 | 225.4 | 105.2 | 39.3 | 97.1 | 18.3 | 10.2 | 3.8 | 5.5 | 2,192.2 |
| **1989** | 0.0 | 4.8 | 55.3 | 149.5 | 452.6 | 167.3 | 574.1 | 96.6 | 104.1 | 32.5 | 129.5 | 10.9 | 4.0 | 2.6 | 1,783.8 |
| **1990** | 1.3 | 33.2 | 57.3 | 220.7 | 201.8 | 480.3 | 129.9 | 370.4 | 66.1 | 102.5 | 9.1 | 60.4 | 8.5 | 4.7 | 1,746.2 |
| **1991** | 1.0 | 60.9 | 40.7 | 85.4 | 141.5 | 156.9 | 396.4 | 51.6 | 217.1 | 22.1 | 114.7 | 15.2 | 74.4 | 60.9 | 1,438.8 |
| **1992** | 0.0 | 79.0 | 721.7 | 143.5 | 98.1 | 125.0 | 145.4 | 276.8 | 109.3 | 165.4 | 59.4 | 50.2 | 14.2 | 91.0 | 2,079.0 |
| **1993** | 0.1 | 9.2 | 275.0 | 1144.5 | 103.0 | 64.3 | 62.2 | 53.5 | 84.9 | 21.8 | 34.5 | 12.6 | 13.1 | 26.5 | 1,905.2 |
| **1994** | 0.3 | 31.5 | 59.8 | 383.4 | 1109.5 | 180.5 | 54.9 | 21.0 | 13.5 | 20.1 | 9.1 | 10.7 | 7.6 | 15.7 | 1,917.5 |
| **1995** | 0.0 | 0.3 | 75.3 | 146.6 | 398.4 | 764.7 | 131.8 | 34.9 | 10.9 | 6.0 | 15.3 | 4.4 | 7.1 | 11.3 | 1,606.9 |
| **1996** | 0.0 | 9.5 | 19.7 | 43.8 | 144.9 | 350.7 | 486.3 | 190.4 | 32.9 | 14.8 | 8.9 | 8.8 | 4.1 | 11.3 | 1,326.1 |
| **1997** | 0.1 | 65.4 | 33.2 | 107.1 | 470.6 | 290.8 | 255.9 | 198.9 | 62.9 | 14.2 | 6.5 | 5.1 | 3.1 | 14.8 | 1,528.8 |
| **1998** | 0.0 | 36.3 | 86.7 | 72.3 | 160.8 | 704.0 | 203.6 | 128.6 | 107.6 | 29.1 | 5.7 | 6.3 | 3.0 | 7.4 | 1,551.5 |
| **1999** | 0.1 | 7.5 | 296.5 | 219.5 | 105.0 | 154.8 | 475.9 | 131.4 | 57.3 | 33.1 | 3.9 | 2.1 | 0.4 | 2.5 | 1,490.0 |
| **2000** | 0.0 | 15.7 | 82.1 | 427.2 | 345.8 | 106.2 | 168.5 | 353.3 | 86.8 | 29.1 | 22.8 | 5.7 | 1.5 | 1.5 | 1,646.3 |
| **2001** | 0.0 | 2.6 | 46.1 | 149.3 | 592.6 | 409.8 | 142.3 | 129.8 | 154.7 | 55.2 | 33.6 | 15.8 | 5.6 | 3.1 | 1,742.3 |

Table 1.4. Numbers of fishery samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-2001, of pollock as sampled by the NMFS observer program.

| | **Strata** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measured | Aleutians | 34,023 | 33,585 | 33,052 | 28,465 | 21,993 | 12,336 | 10,477 | 6,906 | 75 | 70 | 51 |
| males | Northwest | 126,023 | 110,487 | 38,524 | 28,169 | 17,909 | 22,290 | 58,307 | 32,185 | 16,629 | 43,897 | 58,561 |
| | SE A Season | 198,835 | 150,554 | 122,436 | 138,338 | 127,876 | 148,706 | 123,385 | 134,743 | 35,702 | 62,300 | 52,948 |
| | SE B Season | 102,225 | 134,371 | 143,420 | 153,336 | 175,524 | 193,832 | 114,826 | 205,309 | 38,208 | 62,855 | 65,921 |
| Total | | 461,106 | 428,997 | 337,432 | 348,308 | 343,302 | 377,164 | 306,995 | 351,326 | 92,613 | 169,122 | 177,481 |
| Measured | Aleutians | 14,620 | 19,079 | 21,055 | 16,125 | 16,475 | 8,792 | 9,056 | 5,368 | 60 | 114 | 102 |
| Females | Northwest | 124,934 | 114,778 | 39,985 | 28,185 | 19,282 | 22,144 | 51,358 | 39,576 | 19,019 | 42,162 | 63,414 |
| | SE A Season | 184,351 | 142,016 | 112,602 | 146,918 | 124,000 | 140,868 | 102,530 | 108,645 | 31,791 | 55,800 | 50,552 |
| | SE B Season | 90,056 | 136,626 | 135,661 | 146,540 | 150,632 | 149,583 | 105,999 | 174,729 | 35,019 | 40,233 | 58,447 |
| Total | | 413,961 | 412,499 | 309,303 | 337,768 | 310,389 | 321,387 | 268,943 | 295,104 | 85,889 | 138,309 | 172,515 |
| Aged | Aleutians | 22 | 110 | 81 | 157 | 73 | 86 | 15 | 142 | 0 | 0 | 0 |
| males | Northwest | 320 | 179 | 147 | 132 | 123 | 0 | 326 | 216 | 312 | 269 | 257 |
| | SE A Season | 373 | 454 | 451 | 200 | 297 | 470 | 431 | 588 | 533 | 660 | 695 |
| | SE B Season | 248 | 317 | 475 | 571 | 415 | 442 | 284 | 307 | 728 | 833 | 544 |
| Total | | 963 | 1,060 | 1,154 | 1,060 | 908 | 998 | 1,056 | 1,098 | 1,573 | 1,762 | 1,496 |
| Aged | Aleutians | 23 | 121 | 82 | 151 | 105 | 77 | 15 | 166 | 0 | 0 | 1 |
| females | Northwest | 340 | 178 | 153 | 142 | 131 | 0 | 326 | 236 | 312 | 313 | 306 |
| | SE A Season | 385 | 458 | 478 | 201 | 313 | 451 | 434 | 652 | 485 | 616 | 678 |
| | SE B Season | 233 | 332 | 458 | 574 | 392 | 434 | 312 | 308 | 725 | 574 | 465 |
| Total | | 981 | 1,089 | 1,171 | 1,068 | 941 | 962 | 1,087 | 1,192 | 1,522 | 1,504 | 1,450 |

Table 1.5. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-2001.

| Year | Number of Hauls | Lengths | Aged |
|---|---|---|---|
| 1982 | 329 | 40,001 | 1,611 |
| 1983 | 354 | 78,033 | 1,931 |
| 1984 | 355 | 40,530 | 1,806 |
| 1985 | 353 | 48,642 | 1,913 |
| 1986 | 354 | 41,101 | 1,344 |
| 1987 | 342 | 40,144 | 1,607 |
| 1988 | 353 | 40,408 | 1,173 |
| 1989 | 353 | 38,926 | 1,227 |
| 1990 | 352 | 34,814 | 1,257 |
| 1991 | 351 | 43,406 | 1,083 |
| 1992 | 336 | 34,024 | 1,263 |
| 1993 | 355 | 43,278 | 1,385 |
| 1994 | 355 | 38,901 | 1,141 |
| 1995 | 356 | 25,673 | 1,156 |
| 1996 | 355 | 40,789 | 1,387 |
| 1997 | 356 | 35,536 | 1,193 |
| 1998 | 355 | 37,673 | 1,261 |
| 1999 | 353 | 32,532 | 1,385 |
| 2000 | 352 | 41,762 | 1,545 |
| 2001 | 355 | 47,335 | 1,641 |
| 2002 | 355 | 43,361 | 1,695 |

Table 1.6. Biomass (age 1+) of eastern Bering Sea walleye pollock as estimated by surveys 1979-2002 (millions of tons).

| Year | Bottom trawl survey (t) | EIT Survey (t) | EIT Percent age 3+ | Total[3] (t) | Near bottom biomass |
|---|---|---|---|---|---|
| 1979 | 3.20 | 7.46 | (22%) | 10.66 | 30% |
| 1980 | 1.00 | | | | |
| 1981 | 2.30 | | | | |
| 1982 | 2.86 | 4.90 | (95%) | 7.76 | 46% |
| 1983 | 6.24 | | | | |
| 1984 | 4.89 | | | | |
| 1985 | 4.63 | 4.80 | (97%) | 9.43 | 54% |
| 1986 | 4.90 | | | | |
| 1987 | 5.11 | | | | |
| 1988 | 7.11 | 4.68 | (97%) | 11.79 | 63% |
| 1989 | 5.93 | | | | |
| 1990 | 7.13 | | | | |
| 1991 | 5.11 | 1.45 | N/A | 6.56 | 79% |
| 1992 | 4.37 | | | | |
| 1993 | 5.52 | | | | |
| 1994 | 4.98 | 2.89 | (85%) | 7.87 | 64% |
| 1995 | 5.41 | | | | |
| 1996 | 3.20 | 2.31 | (97%) | 5.51 | 60% |
| 1997 | 3.03 | 2.59 | (70%) | 5.62 | 54% |
| 1998 | 2.21 | | | | |
| 1999 | 3.57 | 3.29[4] | (95%) | 6.86 | 52% |
| 2000 | 5.14 | 3.05 | (95%) | 8.19 | 63% |
| 2001 | 4.14 | | | | |
| 2002 | 4.82 | 3.60 | (84%) | 8.42 | 57% |

[3] Although the two survey estimates are added in this table, the stock assessment model treats them as separate, independent indices (survey "$q$'s" are estimated).

[4] This figure excludes the zone near the "horseshoe" area of the EBS (southeast) not usually surveyed, the value including this area was 3.35 million tons.

Table 1.7. Distribution of pollock between areas from summer echo integration-trawl surveys on the Bering Sea shelf, 1994-2002. Data are estimated pollock biomass from 14 m below the surface down to 3 m off bottom. Error bounds only quantify acoustic sampling variability.

| | | | Biomass (million mt) | | | | |
|---|---|---|---|---|---|---|---|
| | | **Area** | | **(percent)** | | **Total Biomass** | **95% Confidence** |
| | **Dates** | (nmi)$^2$ | **SCA** | **E170-SCA** | **W170** | **(million mt)** | **Bounds** |
| **1994** | Jul 9-Aug 19 | 78,251 | 0.312 | 0.399 | 2.18 | 2.89 | NA |
| | | | (11%) | (14%) | (75%) | | |
| **1996** | Jul 20-Aug 30 | 93,810 | 0.215 | 0.269 | 1.83 | 2.31 | 2.15-2.48 |
| | | | (9%) | (12%) | (79%) | | |
| **1997** | Jul 17-Sept 4 | 102,770 | 0.246 | 0.527 | 1.82 | 2.59 | 2.42-2.76 |
| | | | (10%) | (20%) | (70%) | | |
| **1999** | Jun 7-Aug 5 | 103,670 | 0.299 | 0.579 | 2.41 | 3.29 | 2.95-3.62 |
| | | | (9%) | (18%) | (73%) | | |
| **2000** | Jun 7- Aug 2 | 106,140 | 0.393 | 0.498 | 2.16 | 3.05 | 2.88-3.22 |
| | | | (13%) | (16%) | (71%) | | |
| **2002** | Jun 4 – Jul 30 | 99,526 | 0.647 | 0.797 | 2.178 | 3.622 | NA |
| | | | (18%) | (22%) | (60%) | | |

Key: SCA = Sea lion Conservation Area
E170 - SCA = East of 170 W minus SCA
W170 = West of 170 W

Table 1.8. Number of hauls and sample sizes for EBS pollock collected by the EIT surveys.

| Year | Stratum | No. Hauls | No. lengths | No. otoliths collected | No. aged |
|---|---|---|---|---|---|
| 1979 | **Total** | 25 | 7,722 | NA | 2,610 |
| 1982 | **Total** | 48 | 8,687 | NA | 2,741 |
| | Midwater, east of St Paul | 13 | 1,725 | | 783 |
| | Midwater, west of St Paul | 31 | 6,689 | | 1,958 |
| | Bottom | 4 | 273 | | 0 |
| 1985 | **Total** (Legs1 &2) | 73 | 19,872 | NA | 2,739 |
| 1988 | **Total** | 25 | 6,619 | 1,519 | 1,471 |
| 1991 | **Total** | 62 | 16,343 | 2,065 | 1,663 |
| 1994 | **Total** | 77 | 21,506 | 4,973 | 1,770 |
| | East of 170 W | | | | 612 |
| | West of 170 W | | | | 1,158 |
| 1996 | **Total** | 57 | 16,910 | 1,950 | 1,926 |
| | East of 170 W | | | | 815 |
| | West of 170 W | | | | 1,111 |
| 1997 | **Total** | 86 | 30,535 | 3,635 | 2,285 |
| | East of 170 W | | | | 936 |
| | West of 170 W | | | | 1,349 |
| 1999 | **Total** | 122 | 42,364 | 4,946 | 2,446 |
| | East of 170 W | 45 | 13,842 | 1,945 | 946 |
| | West of 170 W | 77 | 28,522 | 3,001 | 1,500 |
| 2000 | **Total** | 128 | 43,729 | 3,459 | 2,253 |
| | East of 170 W | 32 | 7,721 | 850 | 850 |
| | West of 170 W | 96 | 36,008 | 2,609 | 1,403 |
| 2002 | **Total** | 126 | 40,234 | 3,233 | NA |
| | East of 170 W | 48 | 14,601 | 1,424 | NA |
| | West of 170 W | 78 | 25,633 | 1,809 | NA |

Table 1.9. Fishery annual average weights-at-age (kg) as estimated from NMFS observer data. These values are used in the model for computing the predicted fishery catch (in weight) and for computing biomass levels for EBS pollock. NOTE: 2002 weight-at-age is treated as the three-year average of values from 1999-2001.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964-90 | 0.007 | 0.170 | 0.303 | 0.447 | 0.589 | 0.722 | 0.840 | 0.942 | 1.029 | 1.102 | 1.163 | 1.212 | 1.253 | 1.286 | 1.312 |
| 1991 | 0.007 | 0.170 | 0.277 | 0.471 | 0.603 | 0.722 | 0.837 | 0.877 | 0.996 | 1.109 | 1.127 | 1.194 | 1.207 | 1.256 | 1.244 |
| 1992 | 0.007 | 0.170 | 0.387 | 0.454 | 0.615 | 0.660 | 0.745 | 0.898 | 0.960 | 1.151 | 1.174 | 1.203 | 1.132 | 1.184 | 1.304 |
| 1993 | 0.007 | 0.170 | 0.492 | 0.611 | 0.657 | 0.770 | 0.934 | 1.078 | 1.187 | 1.238 | 1.385 | 1.512 | 1.632 | 1.587 | 1.465 |
| 1994 | 0.007 | 0.170 | 0.398 | 0.628 | 0.716 | 0.731 | 0.709 | 0.995 | 1.287 | 1.228 | 1.197 | 1.329 | 1.308 | 1.282 | 1.282 |
| 1995 | 0.007 | 0.170 | 0.389 | 0.505 | 0.733 | 0.841 | 0.854 | 1.000 | 1.235 | 1.314 | 1.375 | 1.488 | 1.402 | 1.336 | 1.491 |
| 1996 | 0.007 | 0.170 | 0.332 | 0.448 | 0.717 | 0.817 | 0.964 | 0.966 | 1.059 | 1.142 | 1.371 | 1.452 | 1.487 | 1.679 | 1.460 |
| 1997 | 0.007 | 0.170 | 0.325 | 0.468 | 0.554 | 0.745 | 0.890 | 1.071 | 1.084 | 1.236 | 1.332 | 1.421 | 1.570 | 1.451 | 1.418 |
| 1998 | 0.007 | 0.170 | 0.362 | 0.574 | 0.629 | 0.636 | 0.778 | 1.046 | 1.173 | 1.242 | 1.236 | 1.337 | 1.443 | 1.487 | 1.709 |
| 1999 | 0.007 | 0.170 | 0.412 | 0.492 | 0.655 | 0.697 | 0.750 | 0.960 | 1.081 | 1.347 | 1.275 | 1.516 | 2.399 | 1.118 | 1.104 |
| 2000 | 0.007 | 0.170 | 0.380 | 0.501 | 0.626 | 0.779 | 0.773 | 0.822 | 1.020 | 1.046 | 1.311 | 1.290 | 1.385 | 1.919 | 1.410 |
| 2001 | 0.007 | 0.170 | 0.275 | 0.512 | 0.678 | 0.818 | 0.990 | 1.055 | 1.073 | 1.195 | 1.279 | 1.468 | 1.592 | 1.444 | 1.619 |
| 2002 | 0.007 | 0.170 | 0.355 | 0.502 | 0.653 | 0.765 | 0.838 | 0.946 | 1.058 | 1.196 | 1.288 | 1.425 | 1.792 | 1.494 | 1.378 |

Table 1.10. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2002.

| Year | Fishery | | Year | Fishery | BTS | EIT |
|---|---|---|---|---|---|---|
| 1964 | 10 | | 1979 | 50 | | 25 |
| 1965 | 10 | | 1980 | 50 | | |
| 1966 | 10 | | 1981 | 50 | | |
| 1967 | 10 | | 1982 | 50 | 100 | 48 |
| 1968 | 10 | | 1983 | 50 | 100 | |
| 1969 | 10 | | 1984 | 50 | 100 | |
| 1970 | 10 | | 1985 | 50 | 100 | 73 |
| 1971 | 10 | | 1986 | 50 | 100 | |
| 1972 | 10 | | 1987 | 50 | 100 | |
| 1973 | 10 | | 1988 | 50 | 100 | 25 |
| 1974 | 10 | | 1989 | 50 | 100 | |
| 1975 | 10 | | 1990 | 50 | 100 | |
| 1976 | 10 | | 1991 | 200 | 100 | 62 |
| 1977 | 10 | | 1992 | 200 | 100 | |
| 1978 | 50 | | 1993 | 200 | 100 | |
| | | | 1994 | 200 | 100 | 77 |
| | | | 1995 | 200 | 100 | |
| | | | 1996 | 200 | 100 | 57 |
| | | | 1997 | 200 | 100 | 86 |
| | | | 1998 | 200 | 100 | |
| | | | 1999 | 200 | 100 | 122 |
| | | | 2000 | 200 | 100 | 128 |
| | | | 2001 | 200 | 100 | |
| | | | 2002 | NA | 100 | 126 |

Table 1.11. Results comparing fits Models 1-7. Effective N (sample size) computations are as presented in McAllister and Ianelli (1997). Note: Model 7 total –ln(likelihood) value is not comparable with others (since survey data are disregarded in the model fitting). See text for additional model descriptions.

| **Fits to data sources** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** |
|---|---|---|---|---|---|---|---|
| ***Total –ln(likelihood)*** | **-1259.68** | **-1248.86** | **-1280.79** | **-1260.00** | **-1257.35** | **-1257.51** | **-1110.10** |
| Number of parameters | 580 | 682 | 657 | 581 | 579 | 580 | 580 |
| ***Age Composition data*** | | | | | | | |
| Effective N Fishery | 189 | 204 | 210 | 190 | 186 | 187 | 218 |
| Effective N Bottom trawl survey | 223 | 205 | 221 | 225 | 230 | 227 | 89 |
| Effective N Hydro acoustic survey | 142 | 131 | 147 | 141 | 143 | 144 | 19 |
| ***Survey abundance estimates, RMSE**** | | | | | | | |
| Trawl Survey | 0.19 | 0.24 | 0.18 | 0.17 | 0.21 | 0.21 | 0.28 |
| EIT survey | 0.32 | 0.31 | 0.32 | 0.32 | 0.33 | 0.33 | 0.57 |
| ***Recruitment Residuals*** | | | | | | | |
| Due to Stock | 0.24 | 0.24 | 0.25 | 0.24 | 0.24 | 0.24 | 0.24 |
| Residual RMSE | 0.38 | 0.39 | 0.37 | 0.38 | 0.39 | 0.40 | 0.43 |
| Total | 0.63 | 0.64 | 0.61 | 0.63 | 0.63 | 0.64 | 0.66 |

*RMSE = $\sqrt{\frac{\sum \ln\left(obs/pred\right)^2}{n}}$

Table 1.12. Results reflecting the stock condition for Models 1-7. Values in parentheses are coefficients of variation (CV's) of values immediately above. See text for model descriptions.

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
|---|---|---|---|---|---|---|---|
| ***Biomass*** | | | | | | | |
| Year 2003 spawning biomass[5] | 3,115 | 3,470 | 2,958 | 3,131 | 3,630 | 3,694 | 2,651 |
| Year 2003 spawning biomass[6] | 3,328 | 3,703 | 3,160 | 3,344 | 3,833 | 3,917 | 2,846 |
| (CV) | (19%) | (16%) | (20%) | (19%) | (17%) | (18%) | (27%) |
| 2002 spawning biomass | 3,681 | 4,211 | 3,458 | 3,704 | 4,255 | 4,404 | 3,618 |
| $B_{msy}$ | 2,293 | 2,455 | 2,279 | 2,301 | 2,536 | 2,569 | 2,238 |
| (CV) | (28%) | (28%) | (29%) | (28%) | (28%) | (26%) | (30%) |
| $B_{40\%}$ | 2,691 | 2,833 | 2,655 | 2,696 | 2,894 | 2,889 | 2,559 |
| (CV) | (19%) | (18%) | (19%) | (19%) | (18%) | (18%) | (19%) |
| Percent of $B_{msy}$ spawning biomass | 136% | 141% | 130% | 136% | 143% | 144% | 118% |
| Percent of $B_{40\%}$ spawning biomass | 124% | 131% | 119% | 124% | 132% | 136% | 111% |
| 2002 Age 3+ Biomass | 11,118 | 12,319 | 10,585 | 11,175 | 12,567 | 13,171 | 10,163 |
| Ratio $B_{2002}/B_{2001}$ (3+ biomass) | 97% | 94% | 97% | 97% | 96% | 96% | 85% |
| ***Recruitment*** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
| Steepness parameter ($h$) | 0.638 | 0.631 | 0.637 | 0.638 | 0.628 | 0.623 | 0.613 |
| Avg Recruitment (all yrs) | 23,026 | 24,036 | 22,821 | 23,064 | 24,454 | 26,615 | 22,607 |
| (CV) | 61% | 63% | 60% | 61% | 62% | 63% | 65% |
| Avg. Recruitment (since 1978) | 25,599 | 26,946 | 25,260 | 25,646 | 27,534 | 30,318 | 24,341 |
| (CV since 1978) | 63% | 65% | 63% | 63% | 64% | 64% | 71% |
| 1996 year class | 42,316 | 53,387 | 40,030 | 42,629 | 46,158 | 50,426 | 55,753 |
| (CV 1996 year class) | (15%) | (13%) | (15%) | (15%) | (15%) | (20%) | (22%) |
| ***Natural Mortality*** | | | | | | | |
| *(age 3 and older)* | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.319 | 0.300 |

Table 1.13. Results relating to yield for Models 1-7. See text for model descriptions.

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
|---|---|---|---|---|---|---|---|
| 2003 Har. Mean Fmsy yield | 2,327 | 2,744 | 2,063 | 2,341 | 2,529 | 2,689 | 2,035 |
| 2003 Fmsy yield | 3,532 | 4,041 | 3,281 | 3,550 | 3,816 | 4,211 | 3,537 |
| (CV) | (44%) | (42%) | (46%) | (44%) | (43%) | (45%) | (51%) |
| Year 2003 F40% Yield | 2,322 | 2,766 | 2,142 | 2,339 | 2,631 | 2,964 | 2,623 |
| Year 2003 F35% Yield | 2,869 | 3,413 | 2,660 | 2,891 | 3,238 | 3,652 | 3,249 |
| MSY (long-term expectation) | 2,112 | 2,175 | 2,104 | 2,114 | 2,240 | 2,387 | 1,831 |
| *Average F(over ages 1-15)* | | | | | | | |
| $F_{msy}$ | 0.60 | 0.59 | 0.59 | 0.59 | 0.50 | 0.57 | 0.80 |
| (CV) | (117%) | (118%) | (125%) | (117%) | (112%) | (121%) | (141%) |
| $F_{40\%}$ | 0.342 | 0.352 | 0.334 | 0.343 | 0.311 | 0.357 | 0.513 |
| Full-selection equivalent F's | | | | | | | |
| $F_{msy}$ | 1.056 | 1.122 | 1.057 | 1.056 | 0.933 | 1.044 | 1.506 |
| ***Harmonic mean*** $F_{msy}$ | 0.516 | 0.542 | 0.470 | 0.515 | 0.478 | 0.485 | 0.539 |
| $F_{40\%}$ | 0.607 | 0.673 | 0.601 | 0.609 | 0.576 | 0.654 | 0.967 |
| $F_{35\%}$ | 0.794 | 0.885 | 0.792 | 0.797 | 0.749 | 0.857 | 1.318 |

[5] At time of spawning, fishing at $F_{msy}$

[6] At time of spawning, fishing at $F_{40\%}$

Table 1.14 Estimates of numbers at age for the EBS pollock stock under Model 1 (millions).

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | 5,017 | 3,930 | 2,249 | 543 | 230 | 358 | 146 | 61 | 33 | 206 |
| 1965 | 20,705 | 2,036 | 2,475 | 1,574 | 335 | 140 | 223 | 93 | 40 | 161 |
| 1966 | 14,682 | 8,402 | 1,282 | 1,735 | 976 | 205 | 87 | 142 | 61 | 135 |
| 1967 | 28,079 | 5,957 | 5,271 | 883 | 1,098 | 621 | 133 | 57 | 95 | 132 |
| 1968 | 25,888 | 11,375 | 3,690 | 3,430 | 494 | 621 | 366 | 80 | 35 | 141 |
| 1969 | 26,753 | 10,488 | 7,050 | 2,408 | 1,931 | 281 | 367 | 220 | 49 | 110 |
| 1970 | 21,319 | 10,818 | 6,437 | 4,429 | 1,425 | 1,149 | 171 | 223 | 133 | 94 |
| 1971 | 9,917 | 8,610 | 6,578 | 3,884 | 2,480 | 804 | 664 | 99 | 128 | 128 |
| 1972 | 11,352 | 3,996 | 5,151 | 3,700 | 1,976 | 1,274 | 427 | 352 | 52 | 132 |
| 1973 | 27,569 | 4,575 | 2,289 | 2,666 | 1,747 | 951 | 630 | 214 | 178 | 95 |
| 1974 | 21,182 | 11,081 | 2,539 | 1,066 | 1,102 | 740 | 417 | 281 | 97 | 125 |
| 1975 | 17,632 | 8,492 | 5,965 | 1,068 | 388 | 413 | 290 | 167 | 114 | 92 |
| 1976 | 13,357 | 7,114 | 4,928 | 2,683 | 412 | 155 | 173 | 125 | 73 | 92 |
| 1977 | 14,589 | 5,397 | 4,206 | 2,449 | 1,180 | 187 | 73 | 83 | 61 | 82 |
| 1978 | 28,102 | 5,902 | 3,240 | 2,265 | 1,196 | 590 | 96 | 38 | 44 | 76 |
| 1979 | 63,568 | 11,392 | 3,592 | 1,840 | 1,112 | 553 | 278 | 46 | 18 | 59 |
| 1980 | 26,082 | 25,774 | 6,953 | 2,074 | 927 | 530 | 268 | 136 | 23 | 39 |
| 1981 | 29,636 | 10,582 | 15,894 | 4,258 | 1,144 | 490 | 284 | 145 | 74 | 34 |
| 1982 | 15,866 | 12,037 | 6,678 | 10,990 | 2,567 | 612 | 253 | 149 | 77 | 58 |
| 1983 | 52,584 | 6,447 | 7,628 | 4,747 | 7,198 | 1,566 | 365 | 153 | 91 | 82 |
| 1984 | 12,573 | 21,369 | 4,091 | 5,472 | 3,195 | 4,583 | 980 | 231 | 97 | 110 |
| 1985 | 34,535 | 5,109 | 13,566 | 2,944 | 3,742 | 2,057 | 2,825 | 597 | 143 | 126 |
| 1986 | 12,700 | 14,034 | 3,244 | 9,767 | 2,015 | 2,412 | 1,270 | 1,723 | 371 | 165 |
| 1987 | 7,453 | 5,161 | 8,911 | 2,338 | 6,703 | 1,306 | 1,499 | 780 | 1,079 | 332 |
| 1988 | 4,449 | 3,029 | 3,282 | 6,476 | 1,642 | 4,564 | 864 | 960 | 501 | 910 |
| 1989 | 9,421 | 1,808 | 1,924 | 2,366 | 4,448 | 1,079 | 2,881 | 521 | 581 | 861 |
| 1990 | 54,551 | 3,829 | 1,148 | 1,385 | 1,617 | 2,901 | 674 | 1,713 | 311 | 869 |
| 1991 | 26,251 | 22,172 | 2,431 | 820 | 932 | 973 | 1,658 | 358 | 934 | 648 |
| 1992 | 20,574 | 10,669 | 14,069 | 1,728 | 545 | 546 | 538 | 844 | 188 | 828 |
| 1993 | 51,914 | 8,361 | 6,763 | 9,918 | 1,124 | 305 | 285 | 254 | 413 | 504 |
| 1994 | 13,824 | 21,102 | 5,319 | 4,923 | 6,459 | 619 | 140 | 141 | 135 | 519 |
| 1995 | 10,815 | 5,619 | 13,432 | 3,889 | 3,313 | 3,835 | 321 | 77 | 81 | 398 |
| 1996 | 26,563 | 4,397 | 3,578 | 9,853 | 2,681 | 2,078 | 2,172 | 190 | 47 | 308 |
| 1997 | 42,316 | 10,798 | 2,797 | 2,617 | 6,995 | 1,820 | 1,245 | 1,175 | 106 | 208 |
| 1998 | 17,472 | 17,201 | 6,870 | 2,047 | 1,861 | 4,765 | 1,099 | 682 | 662 | 184 |
| 1999 | 17,447 | 7,102 | 10,946 | 5,032 | 1,460 | 1,277 | 2,930 | 618 | 393 | 496 |
| 2000 | 24,486 | 7,092 | 4,522 | 8,001 | 3,539 | 975 | 804 | 1,749 | 367 | 556 |
| 2001 | 25,693 | 9,954 | 4,514 | 3,298 | 5,579 | 2,323 | 598 | 464 | 1,002 | 563 |
| 2002 | 11,111 | 10,444 | 6,334 | 3,287 | 2,285 | 3,614 | 1,396 | 336 | 258 | 927 |
| Median | 20,705 | 8,402 | 4,928 | 2,683 | 1,642 | 951 | 417 | 220 | 106 | 141 |
| Average | 23,026 | 9,324 | 5,688 | 3,714 | 2,309 | 1,392 | 766 | 417 | 235 | 297 |

Table 1.15. Estimated catch-at-age of EBS pollock for Model 1 (millions).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
|---|---|---|---|---|---|---|---|---|---|---|
| **1964** | 7 | 39 | 108 | 79 | 36 | 50 | 18 | 6 | 3 | 16 |
| **1965** | 26 | 20 | 115 | 223 | 51 | 19 | 26 | 9 | 4 | 12 |
| **1966** | 20 | 109 | 78 | 219 | 119 | 22 | 8 | 13 | 5 | 11 |
| **1967** | 67 | 137 | 556 | 188 | 226 | 111 | 22 | 9 | 14 | 18 |
| **1968** | 61 | 256 | 380 | 717 | 100 | 109 | 59 | 12 | 5 | 19 |
| **1969** | 95 | 317 | 929 | 421 | 330 | 44 | 58 | 35 | 8 | 21 |
| **1970** | 94 | 405 | 1,037 | 941 | 296 | 219 | 33 | 43 | 26 | 21 |
| **1971** | 59 | 430 | 1,378 | 1,061 | 663 | 198 | 165 | 25 | 32 | 36 |
| **1972** | 66 | 329 | 1,352 | 1,172 | 605 | 370 | 121 | 97 | 14 | 35 |
| **1973** | 208 | 480 | 743 | 1,033 | 655 | 339 | 219 | 73 | 60 | 31 |
| **1974** | 194 | 1,398 | 961 | 477 | 478 | 307 | 168 | 111 | 38 | 48 |
| **1975** | 89 | 618 | 2,050 | 449 | 156 | 157 | 106 | 60 | 40 | 31 |
| **1976** | 54 | 418 | 1,416 | 955 | 140 | 50 | 53 | 37 | 21 | 26 |
| **1977** | 47 | 255 | 1,001 | 728 | 335 | 50 | 19 | 21 | 15 | 19 |
| **1978** | 54 | 217 | 658 | 667 | 392 | 187 | 30 | 12 | 13 | 23 |
| **1979** | 115 | 394 | 689 | 514 | 346 | 167 | 82 | 13 | 5 | 16 |
| **1980** | 36 | 683 | 1,045 | 460 | 231 | 127 | 63 | 32 | 5 | 9 |
| **1981** | 20 | 88 | 916 | 689 | 277 | 130 | 72 | 36 | 18 | 8 |
| **1982** | 6 | 60 | 233 | 1,104 | 394 | 104 | 41 | 23 | 12 | 9 |
| **1983** | 17 | 25 | 208 | 376 | 877 | 211 | 47 | 19 | 11 | 10 |
| **1984** | 4 | 75 | 100 | 365 | 363 | 668 | 151 | 32 | 14 | 17 |
| **1985** | 11 | 18 | 330 | 195 | 422 | 298 | 433 | 83 | 21 | 20 |
| **1986** | 4 | 47 | 76 | 622 | 219 | 337 | 188 | 231 | 52 | 25 |
| **1987** | 1 | 12 | 147 | 105 | 470 | 121 | 176 | 90 | 122 | 37 |
| **1988** | 1 | 10 | 76 | 408 | 160 | 586 | 140 | 152 | 78 | 138 |
| **1989** | 3 | 6 | 47 | 159 | 461 | 147 | 494 | 88 | 96 | 139 |
| **1990** | 11 | 13 | 36 | 110 | 263 | 577 | 166 | 393 | 74 | 191 |
| **1991** | 6 | 87 | 85 | 73 | 169 | 215 | 452 | 91 | 247 | 159 |
| **1992** | 6 | 50 | 589 | 182 | 116 | 141 | 171 | 250 | 58 | 235 |
| **1993** | 8 | 16 | 102 | 1,039 | 251 | 101 | 82 | 63 | 91 | 97 |
| **1994** | 2 | 29 | 60 | 391 | 1,114 | 162 | 32 | 27 | 23 | 78 |
| **1995** | 1 | 6 | 114 | 234 | 440 | 785 | 56 | 11 | 11 | 45 |
| **1996** | 3 | 8 | 39 | 355 | 193 | 345 | 510 | 41 | 10 | 54 |
| **1997** | 5 | 19 | 30 | 91 | 487 | 292 | 283 | 246 | 22 | 35 |
| **1998** | 2 | 27 | 67 | 65 | 119 | 703 | 231 | 131 | 124 | 29 |
| **1999** | 2 | 9 | 126 | 221 | 125 | 166 | 494 | 107 | 57 | 63 |
| **2000** | 3 | 10 | 60 | 406 | 349 | 145 | 155 | 345 | 61 | 80 |
| **2001** | 3 | 16 | 67 | 185 | 607 | 380 | 126 | 100 | 184 | 89 |
| **2002** | 2 | 19 | 109 | 213 | 285 | 675 | 335 | 82 | 54 | 169 |
| **Median** | 11 | 50 | 147 | 391 | 296 | 167 | 121 | 43 | 22 | 31 |
| **Average** | 36 | 183 | 464 | 459 | 342 | 252 | 156 | 83 | 45 | 54 |

Table 1.16. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for Model 1 (current assessment) compared to estimates from the 2001-1997 assessments for EBS pollock. NOTE: see Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

| Age 3+ Biomass | Current Assessment | CV | 2001 Assess. | CV | 2000 Assess. | CV | 1999 Assess. | CV | 1998 Assess. | CV | 1997 Assess. | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | 1,784 | 46% | 1,726 | 46% | 751 | 35% | 917 | 41% | 1,037 | 30% | | |
| 1965 | 2,266 | 40% | 2,196 | 40% | 976 | 36% | 976 | 32% | 1,227 | 26% | | |
| 1966 | 2,324 | 40% | 2,251 | 41% | 1,001 | 39% | 919 | 31% | 1,096 | 28% | | |
| 1967 | 3,511 | 33% | 3,420 | 33% | 1,957 | 34% | 1,858 | 24% | 2,095 | 22% | | |
| 1968 | 3,976 | 34% | 3,876 | 34% | 2,312 | 36% | 2,312 | 27% | 2,510 | 23% | | |
| 1969 | 5,252 | 32% | 5,137 | 32% | 3,379 | 29% | 3,579 | 22% | 3,810 | 19% | | |
| 1970 | 6,201 | 30% | 6,079 | 30% | 3,998 | 25% | 4,479 | 19% | 5,083 | 15% | | |
| 1971 | 6,702 | 27% | 6,580 | 28% | 4,372 | 21% | 5,161 | 16% | 5,813 | 12% | | |
| 1972 | 6,194 | 26% | 6,078 | 27% | 3,984 | 19% | 4,896 | 15% | 5,648 | 11% | | |
| 1973 | 4,626 | 31% | 4,520 | 32% | 2,873 | 26% | 3,357 | 20% | 3,922 | 14% | | |
| 1974 | 3,287 | 38% | 3,193 | 39% | 1,648 | 41% | 1,952 | 28% | 2,342 | 19% | | |
| 1975 | 3,436 | 27% | 3,366 | 26% | 2,536 | 23% | 2,683 | 18% | 3,014 | 13% | | |
| 1976 | 3,492 | 22% | 3,434 | 22% | 2,694 | 17% | 2,748 | 16% | 3,008 | 13% | | |
| 1977 | 3,496 | 20% | 3,444 | 20% | 2,701 | 13% | 2,716 | 14% | 2,894 | 13% | | |
| 1978 | 3,375 | 20% | 3,327 | 19% | 2,608 | 14% | 2,668 | 15% | 2,867 | 13% | 3,244 | 19% |
| 1979 | 3,329 | 19% | 3,280 | 19% | 2,640 | 16% | 2,720 | 16% | 2,933 | 15% | 3,183 | 21% |
| 1980 | 4,385 | 16% | 4,322 | 16% | 3,723 | 15% | 3,888 | 16% | 4,294 | 14% | 4,618 | 19% |
| 1981 | 8,239 | 14% | 8,127 | 14% | 7,834 | 12% | 8,064 | 13% | 8,569 | 12% | 9,190 | 16% |
| 1982 | 9,388 | 13% | 9,261 | 13% | 9,021 | 13% | 9,229 | 13% | 9,778 | 12% | 10,524 | 17% |
| 1983 | 10,441 | 13% | 10,298 | 13% | 9,958 | 12% | 10,153 | 12% | 10,705 | 12% | 11,555 | 16% |
| 1984 | 10,143 | 13% | 10,000 | 13% | 9,518 | 13% | 9,685 | 12% | 10,179 | 12% | 11,028 | 17% |
| 1985 | 12,344 | 11% | 12,181 | 11% | 11,182 | 10% | 11,370 | 10% | 11,919 | 11% | 12,853 | 15% |
| 1986 | 11,538 | 11% | 11,381 | 11% | 10,277 | 10% | 10,440 | 10% | 10,913 | 11% | 11,796 | 16% |
| 1987 | 12,116 | 10% | 11,951 | 10% | 10,636 | 9% | 10,769 | 9% | 11,116 | 10% | 11,952 | 15% |
| 1988 | 11,317 | 10% | 11,159 | 10% | 9,910 | 8% | 9,991 | 9% | 10,274 | 10% | 11,020 | 15% |
| 1989 | 9,540 | 10% | 9,394 | 10% | 8,251 | 9% | 8,305 | 9% | 8,546 | 10% | 9,210 | 16% |
| 1990 | 7,524 | 11% | 7,393 | 11% | 6,473 | 10% | 6,497 | 10% | 6,659 | 12% | 7,240 | 18% |
| 1991 | 5,708 | 13% | 5,582 | 12% | 4,859 | 11% | 4,842 | 11% | 5,180 | 13% | 5,690 | 20% |
| 1992 | 9,227 | 10% | 8,898 | 10% | 7,920 | 9% | 7,800 | 10% | 8,294 | 13% | 9,465 | 21% |
| 1993 | 12,110 | 10% | 11,503 | 10% | 10,233 | 10% | 9,873 | 10% | 10,279 | 16% | 12,086 | 25% |
| 1994 | 11,358 | 11% | 10,590 | 11% | 9,285 | 10% | 8,622 | 12% | 8,917 | 18% | 10,626 | 29% |
| 1995 | 13,848 | 12% | 12,617 | 13% | 10,267 | 12% | 8,817 | 15% | 8,680 | 22% | 9,998 | 32% |
| 1996 | 11,988 | 13% | 10,752 | 14% | 8,556 | 14% | 7,147 | 17% | 6,811 | 26% | 8,142 | 36% |
| 1997 | 10,142 | 15% | 8,984 | 16% | 7,057 | 17% | 5,710 | 22% | 5,307 | 31% | 6,631 | 42% |
| 1998 | 10,466 | 17% | 9,335 | 20% | 7,448 | 22% | 5,961 | 28% | 5,133 | 39% | 5,133 | 39% |
| 1999 | 12,712 | 21% | 12,593 | 28% | 10,772 | 30% | 7,513 | 36% | | | | |
| 2000 | 11,807 | 24% | 11,680 | 33% | 10,490 | 34% | | | | | | |
| 2001 | 11,511 | 27% | 11,145 | 39% | | | | | | | | |
| 2002 | 11,118 | 33% | | | | | | | | | | |

Table 1.17 Projections of Model 1 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 6,886; 2,691; and 2,410 t, respectively.

| *Sp.Biomass* | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
|---|---|---|---|---|---|---|---|
| 2002 | 3,681 | 3,681 | 3,681 | 3,681 | 3,681 | 3,681 | 3,681 |
| 2003 | 3,328 | 3,328 | 3,483 | 3,499 | 3,647 | 3,237 | 3,328 |
| 2004 | 2,785 | 2,785 | 3,316 | 3,378 | 4,011 | 2,541 | 2,785 |
| 2005 | 2,480 | 2,480 | 3,174 | 3,266 | 4,301 | 2,237 | 2,430 |
| 2006 | 2,481 | 2,481 | 3,186 | 3,291 | 4,627 | 2,258 | 2,323 |
| 2007 | 2,657 | 2,657 | 3,367 | 3,471 | 5,050 | 2,434 | 2,454 |
| 2008 | 2,807 | 2,807 | 3,556 | 3,662 | 5,473 | 2,562 | 2,569 |
| 2009 | 2,865 | 2,865 | 3,671 | 3,783 | 5,812 | 2,597 | 2,599 |
| 2010 | 2,861 | 2,861 | 3,711 | 3,829 | 6,020 | 2,579 | 2,580 |
| 2011 | 2,856 | 2,856 | 3,736 | 3,859 | 6,202 | 2,569 | 2,569 |
| 2012 | 2,870 | 2,870 | 3,773 | 3,902 | 6,396 | 2,583 | 2,583 |
| 2013 | 2,896 | 2,896 | 3,812 | 3,946 | 6,548 | 2,607 | 2,607 |
| 2014 | 2,903 | 2,903 | 3,829 | 3,967 | 6,634 | 2,612 | 2,612 |
| 2015 | 2,889 | 2,889 | 3,829 | 3,970 | 6,734 | 2,596 | 2,596 |
| *F* | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2002 | 0.187 | 0.187 | 0.187 | 0.187 | 0.187 | 0.187 | 0.187 |
| 2003 | 0.342 | 0.342 | 0.171 | 0.154 | 0.000 | 0.448 | 0.342 |
| 2004 | 0.342 | 0.342 | 0.171 | 0.154 | 0.000 | 0.412 | 0.342 |
| 2005 | 0.303 | 0.303 | 0.171 | 0.154 | 0.000 | 0.358 | 0.389 |
| 2006 | 0.291 | 0.291 | 0.166 | 0.154 | 0.000 | 0.351 | 0.360 |
| 2007 | 0.297 | 0.297 | 0.165 | 0.154 | 0.000 | 0.365 | 0.368 |
| 2008 | 0.305 | 0.305 | 0.166 | 0.154 | 0.000 | 0.378 | 0.379 |
| 2009 | 0.308 | 0.308 | 0.166 | 0.154 | 0.000 | 0.382 | 0.383 |
| 2010 | 0.309 | 0.309 | 0.167 | 0.154 | 0.000 | 0.383 | 0.383 |
| 2011 | 0.310 | 0.310 | 0.167 | 0.154 | 0.000 | 0.382 | 0.382 |
| 2012 | 0.310 | 0.310 | 0.167 | 0.154 | 0.000 | 0.382 | 0.382 |
| 2013 | 0.311 | 0.311 | 0.168 | 0.154 | 0.000 | 0.384 | 0.384 |
| 2014 | 0.311 | 0.311 | 0.168 | 0.154 | 0.000 | 0.384 | 0.384 |
| 2015 | 0.310 | 0.310 | 0.168 | 0.154 | 0.000 | 0.383 | 0.383 |
| *Catch* | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2002 | 1,485 | 1,485 | 1,485 | 1,485 | 1,485 | 1,485 | 1,485 |
| 2003 | 2,322 | 2,322 | 1,280 | 1,162 | 0 | 2,869 | 2,322 |
| 2004 | 1,864 | 1,864 | 1,206 | 1,114 | 0 | 1,968 | 1,864 |
| 2005 | 1,444 | 1,444 | 1,144 | 1,069 | 0 | 1,477 | 1,777 |
| 2006 | 1,344 | 1,344 | 1,090 | 1,050 | 0 | 1,415 | 1,506 |
| 2007 | 1,427 | 1,427 | 1,107 | 1,071 | 0 | 1,544 | 1,571 |
| 2008 | 1,556 | 1,556 | 1,173 | 1,124 | 0 | 1,692 | 1,699 |
| 2009 | 1,645 | 1,645 | 1,245 | 1,188 | 0 | 1,773 | 1,775 |
| 2010 | 1,674 | 1,674 | 1,288 | 1,230 | 0 | 1,784 | 1,784 |
| 2011 | 1,672 | 1,672 | 1,305 | 1,246 | 0 | 1,768 | 1,768 |
| 2012 | 1,671 | 1,671 | 1,315 | 1,256 | 0 | 1,768 | 1,768 |
| 2013 | 1,681 | 1,681 | 1,324 | 1,264 | 0 | 1,785 | 1,785 |
| 2014 | 1,694 | 1,694 | 1,333 | 1,273 | 0 | 1,796 | 1,796 |
| 2015 | 1,694 | 1,694 | 1,339 | 1,281 | 0 | 1,794 | 1,794 |

Table 1.18. Analysis of ecosystem considerations for BSAI pollock and the pollock fishery.

| Indicator | Observation | Interpretation | Evaluation |
|---|---|---|---|
| **Ecosystem effects on EBS pollock** | | | |
| *Prey availability or abundance trends* | | | |
| Zooplankton | Stomach contents, ichthyoplankton surveys, changes mean wt-at-age | Stable, data limited | Probably no concern |
| *Predator population trends* | | | |
| Marine mammals | Fur seals declining, Steller sea lions increasing slightly | Possibly lower mortality on pollock | Probably no concern |
| Birds | Stable, some increasing some decreasing | Affects young-of-year mortality | Probably no concern |
| Fish (Pollock, Pacific cod, halibut) | Stable to increasing | Possible increases to pollock mortality | |
| *Changes in habitat quality* | | | |
| Temperature regime | Cold years pollock distribution towards NW on average | Likely to affect surveyed stock | No concern (dealt with in model) |
| Winter-spring environmental conditions | Affects pre-recruit survival | Probably a number of factors | Causes natural variability |
| Production | Fairly stable nutrient flow from upwelled BS Basin | Inter-annual variability low | No concern |
| **Fishery effects on ecosystem** | | | |
| *Fishery contribution to bycatch* | | | |
| Prohibited species | Stable, heavily monitored | Likely to be safe | No concern |
| Forage (including herring, Atka mackerel, cod, and pollock) | Stable, heavily monitored | Likely to be safe | No concern |
| HAPC biota | Likely minor impact | Likely to be safe | No concern |
| Marine mammals and birds | Very minor direct-take | Safe | No concern |
| Sensitive non-target species | Likely minor impact | Data limited, likely to be safe | No concern |
| *Fishery concentration in space and time* | Generally more diffuse | Mixed potential impact (fur seals vs Steller sea lions) | Possible concern |
| *Fishery effects on amount of large size target fish* | Depends on highly variable year-class strength | Natural fluctuation | Probably no concern |
| *Fishery contribution to discards and offal production* | Decreasing | Improving, but data limited | Possible concern |
| *Fishery effects on age-at-maturity and fecundity* | New study initiated in 2002 | NA | Possible concern |

Table 1.19. Summary results for Model 1, EBS pollock. Tonnage units are thousands of metric tons.

| Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *M* | 0.900 | 0.450 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 |
| Prop. F. Mature | 0.000 | 0.004 | 0.145 | 0.321 | 0.421 | 0.451 | 0.474 | 0.482 | 0.485 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 |
| Fish. Selectivity | 0.001 | 0.014 | 0.097 | 0.367 | 0.879 | 1.592 | 1.773 | 1.605 | 1.402 | 1.259 | 1.202 | 1.202 | 1.202 | 1.202 | 1.202 |

| | **Model 1** |
|---|---|
| 2002 Spawning biomass | **3,681** t |
| $B_{msy}$ | **2,293** t |
| $B_{40\%}$ | **2,691** t |
| $B_{35\%}$ | **2,410** t |

| **Yield Considerations** | |
|---|---|
| Year 2002 Harmonic Mean $F_{msy}$ Yield | **2,327** t |
| Year 2002 Yield F40% (adjusted) | **2,322** t |
| Full Selection F's | |
| $F_{msy}$ | **1.056** |
| $F_{40\%}$ | **0.607** |
| $F_{35\%}$ | **0.794** |

## 1.13. Figures

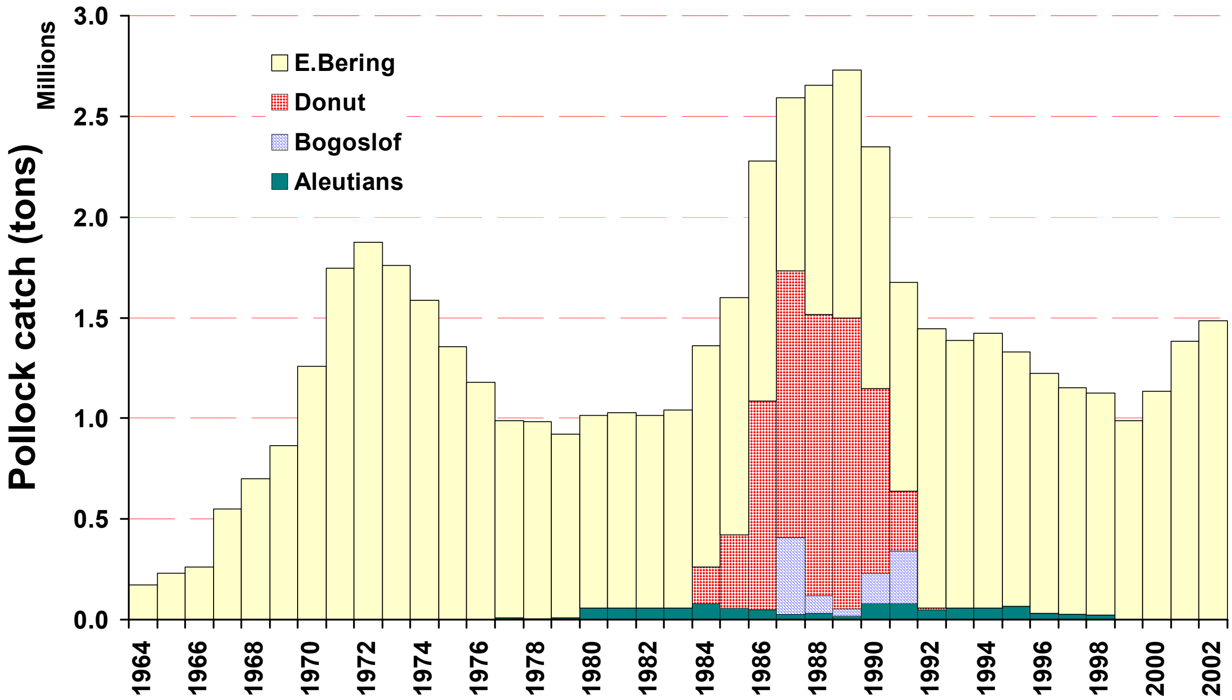



Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-2002.

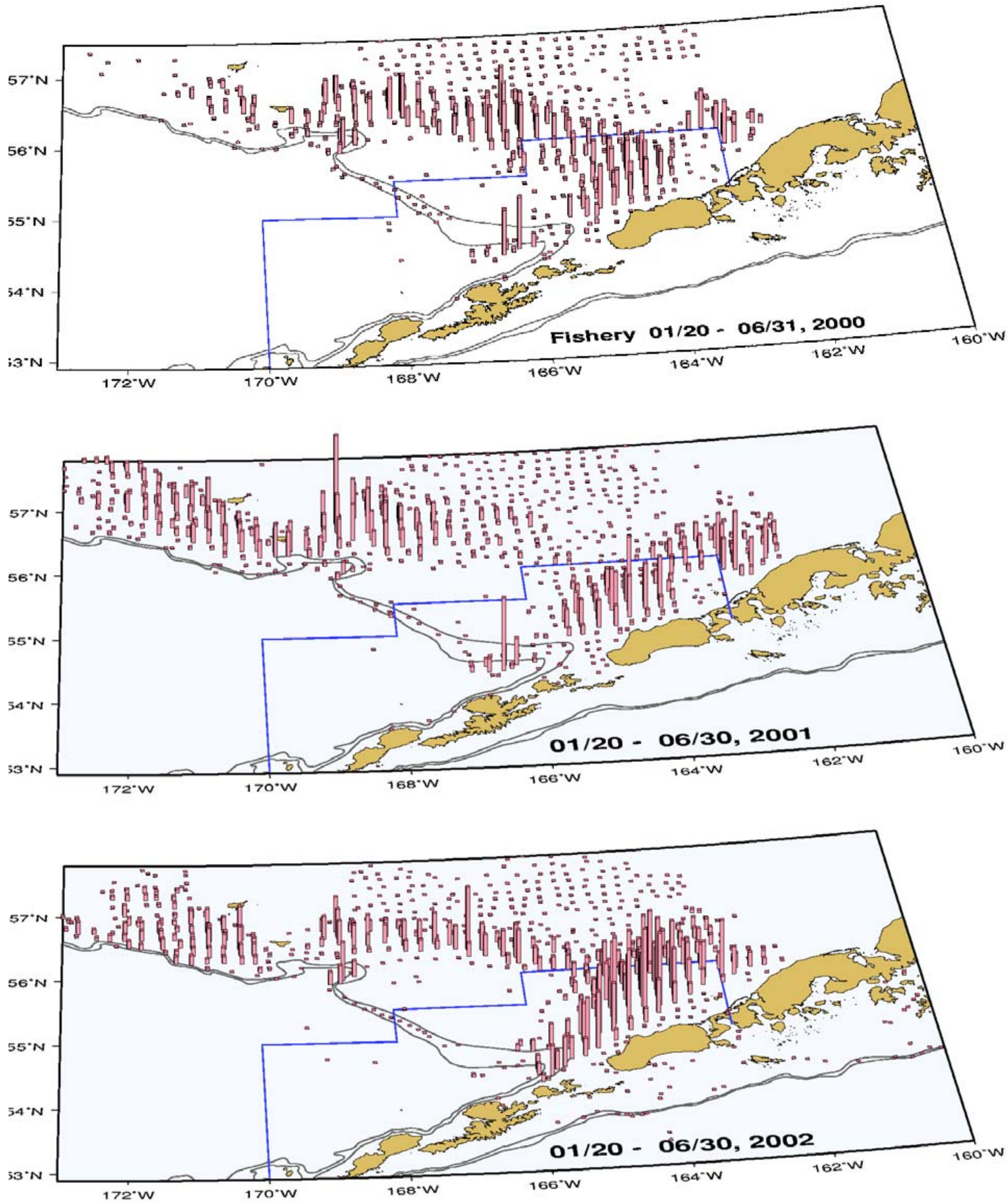



Figure 1.2. Concentrations of the pollock fishery 2000-2002, January - June on the EBS shelf. Line delineates SCA (sea lion conservation area). The column height represents relative removal on the same scale in all years.

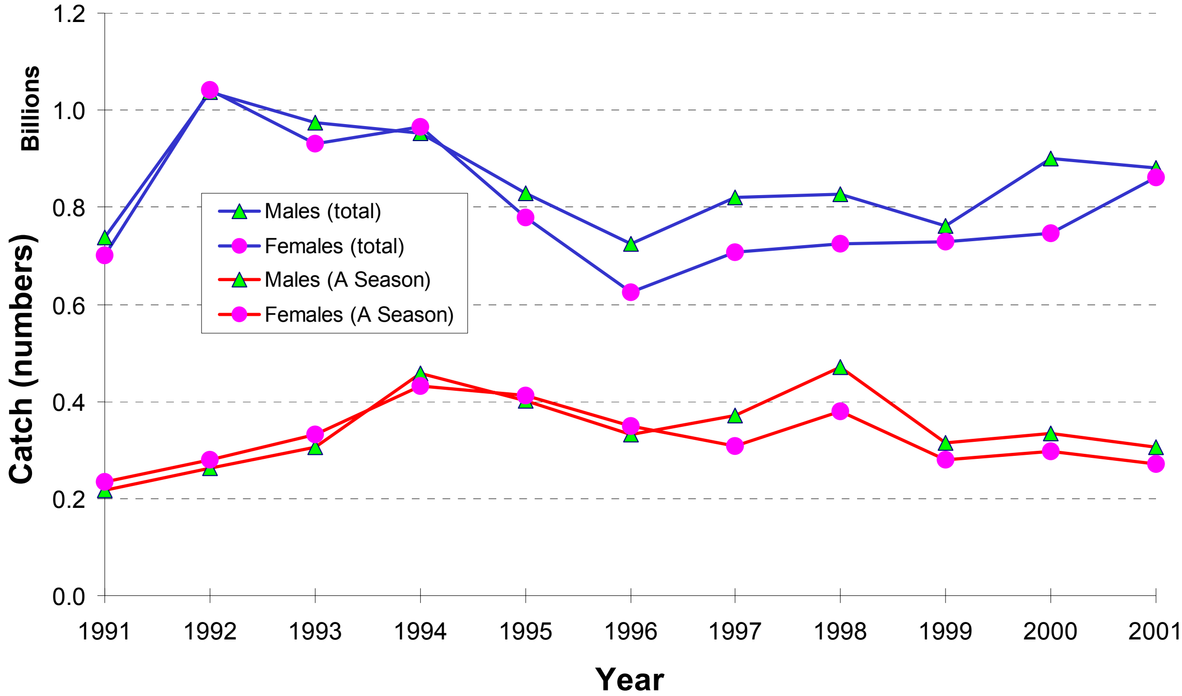



Figure 1.3. Estimate of EBS pollock catch numbers by sex for the “A season” (January-June) and for the entire annual fishery, 1991-2001.

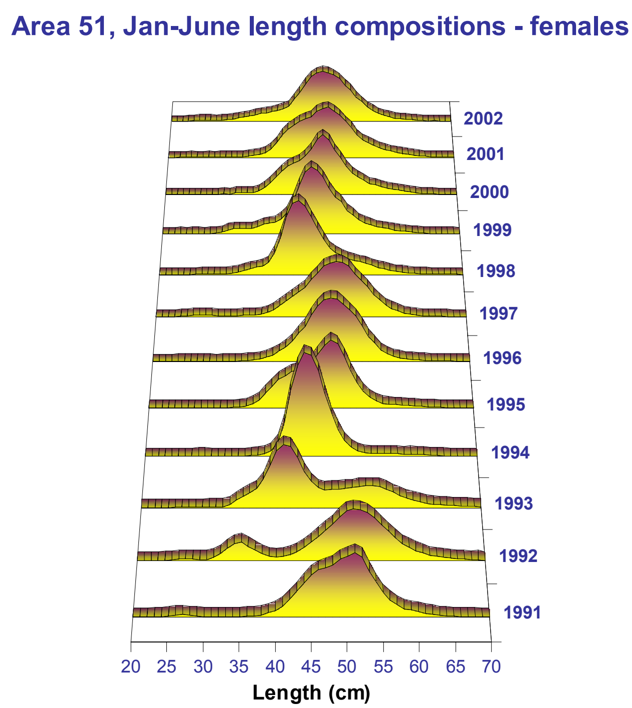



Figure 1.4. Fishery length frequency for the “A season” (January-June) EBS pollock, 1991-2002. Data for 2002 are preliminary.

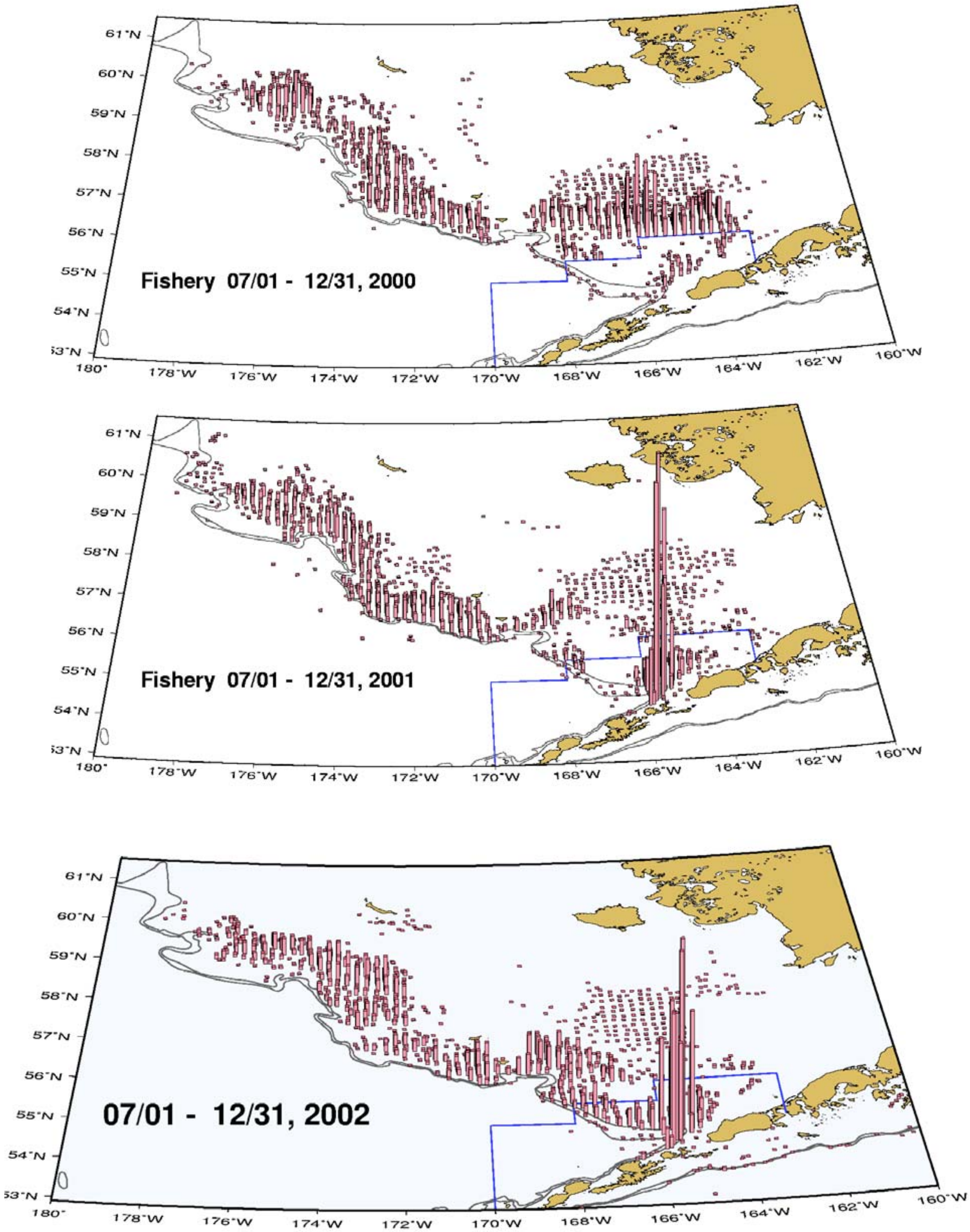



Figure 1.5. Concentrations of the pollock fishery 2000-2002, July – December on the EBS shelf. Line delineates SCA (sea lion conservation area). The density represents relative removal on the same scale over all years.

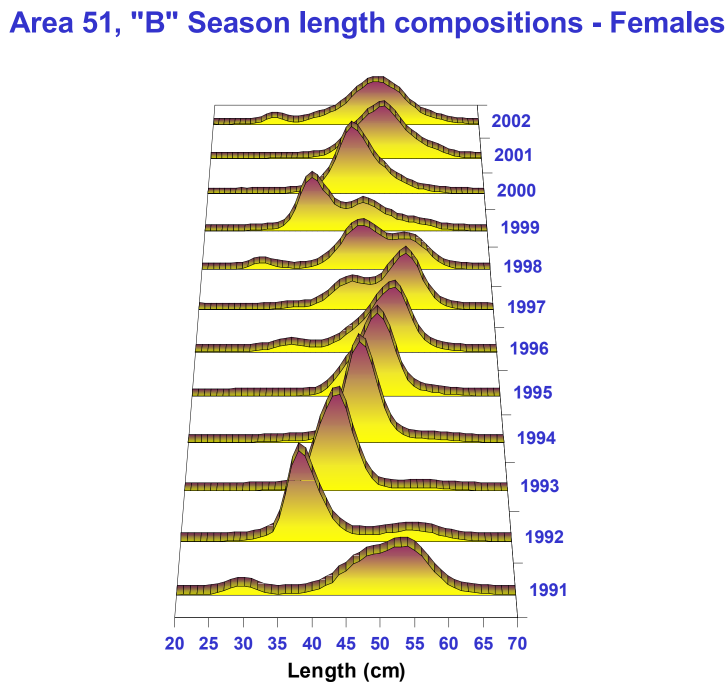



Figure 1.6. Length frequency of EBS pollock observed in period July-December for 1991-2002. Data for 2002 are preliminary.

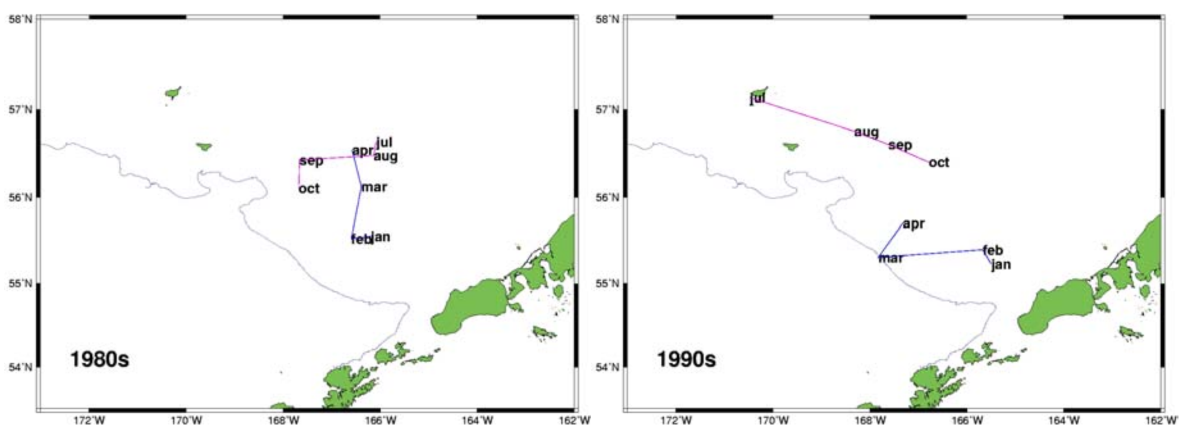



Figure 1.7. Average centers of monthly pollock catch-distribution based on NMFS observer data during the 1980s (top) and the 1990s (bottom).

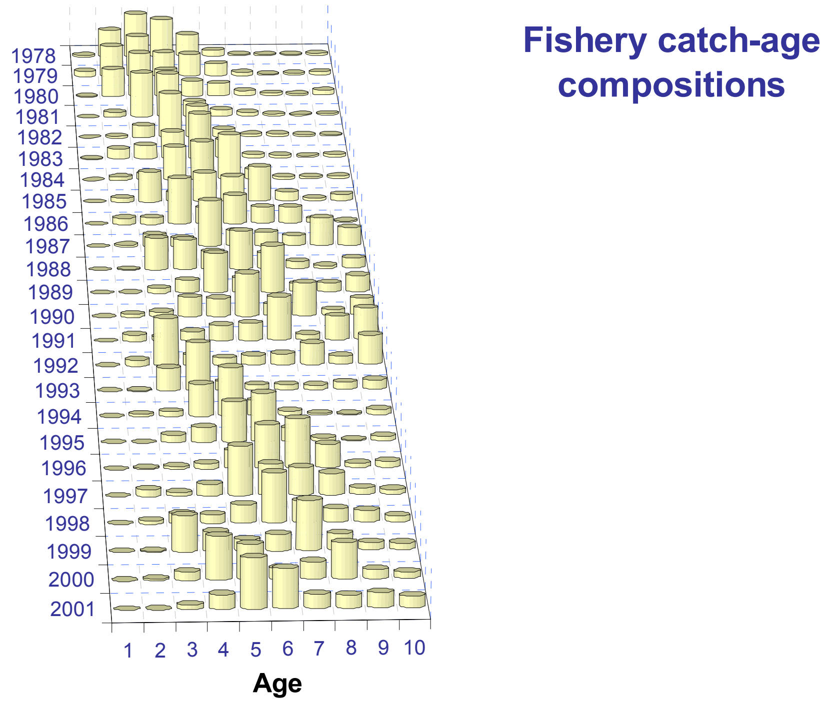



Figure 1.8. EBS walleye pollock fishery estimated catch-at-age data (proportions) for 1978-2001. Age 10 represents pollock age 10 and older.

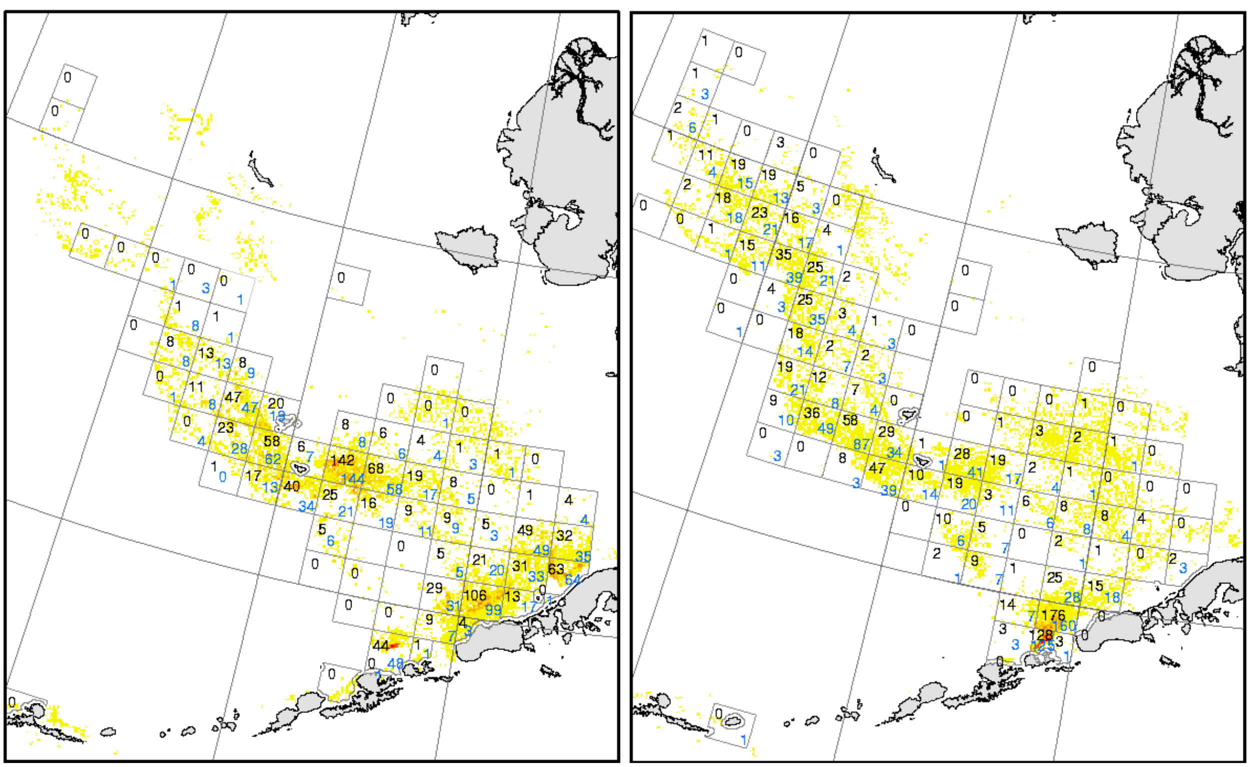


Figure 1.9. Sampling effort for lengths (upper left corner of grids) and otoliths (lower right corner of grids) of pollock in the EBS during 2001. Values are expressed as the number-per-thousand of samples within each cell divided by the total number of collections for Jan-June (left panel) and July-Dec (right panel).

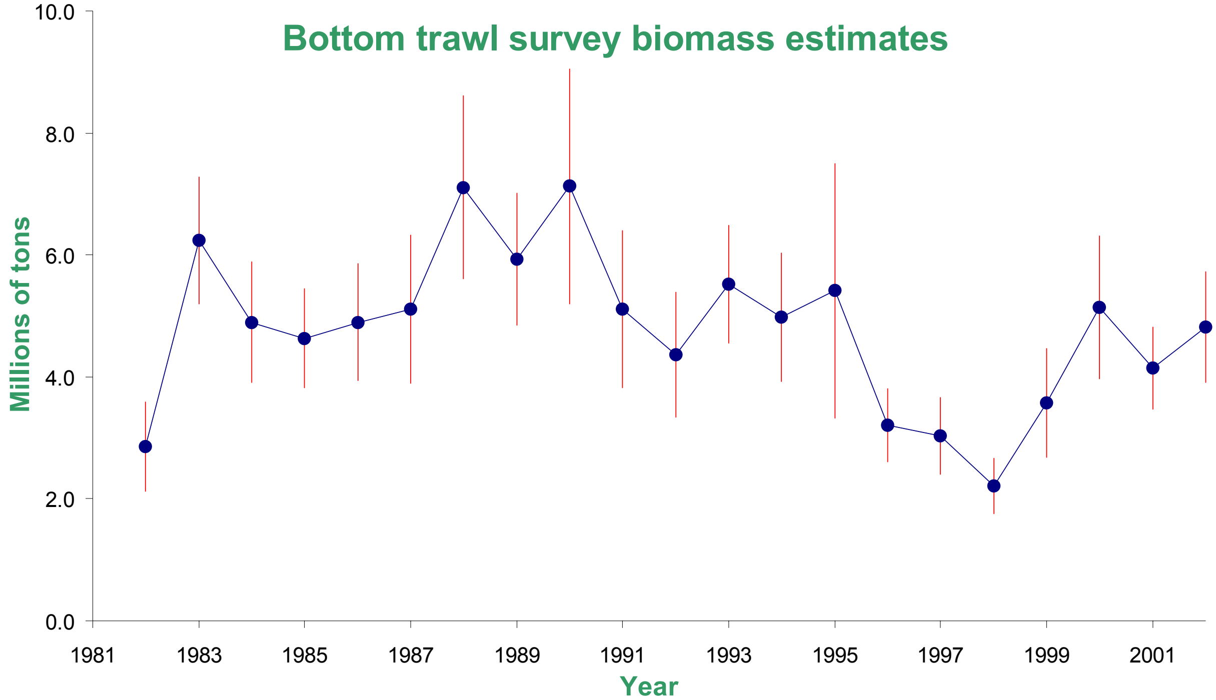



Figure 1.10. Bottom-trawl survey biomass estimates with approximate 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1982-2002.

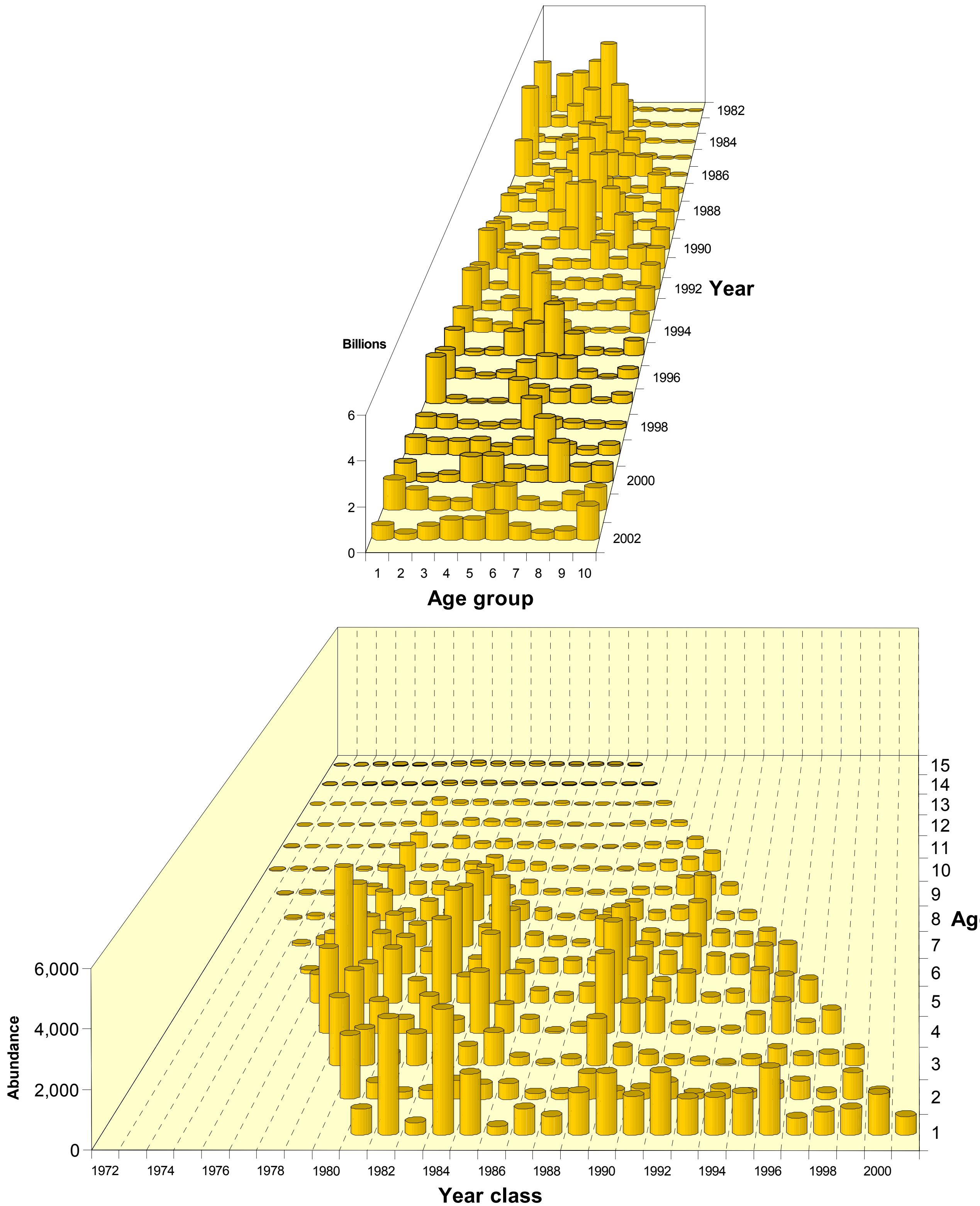



Figure 1.11. Abundance levels by age and year plotted over time (top) and by individual cohorts (year classes) as estimated directly from the NMFS bottom-trawl surveys.

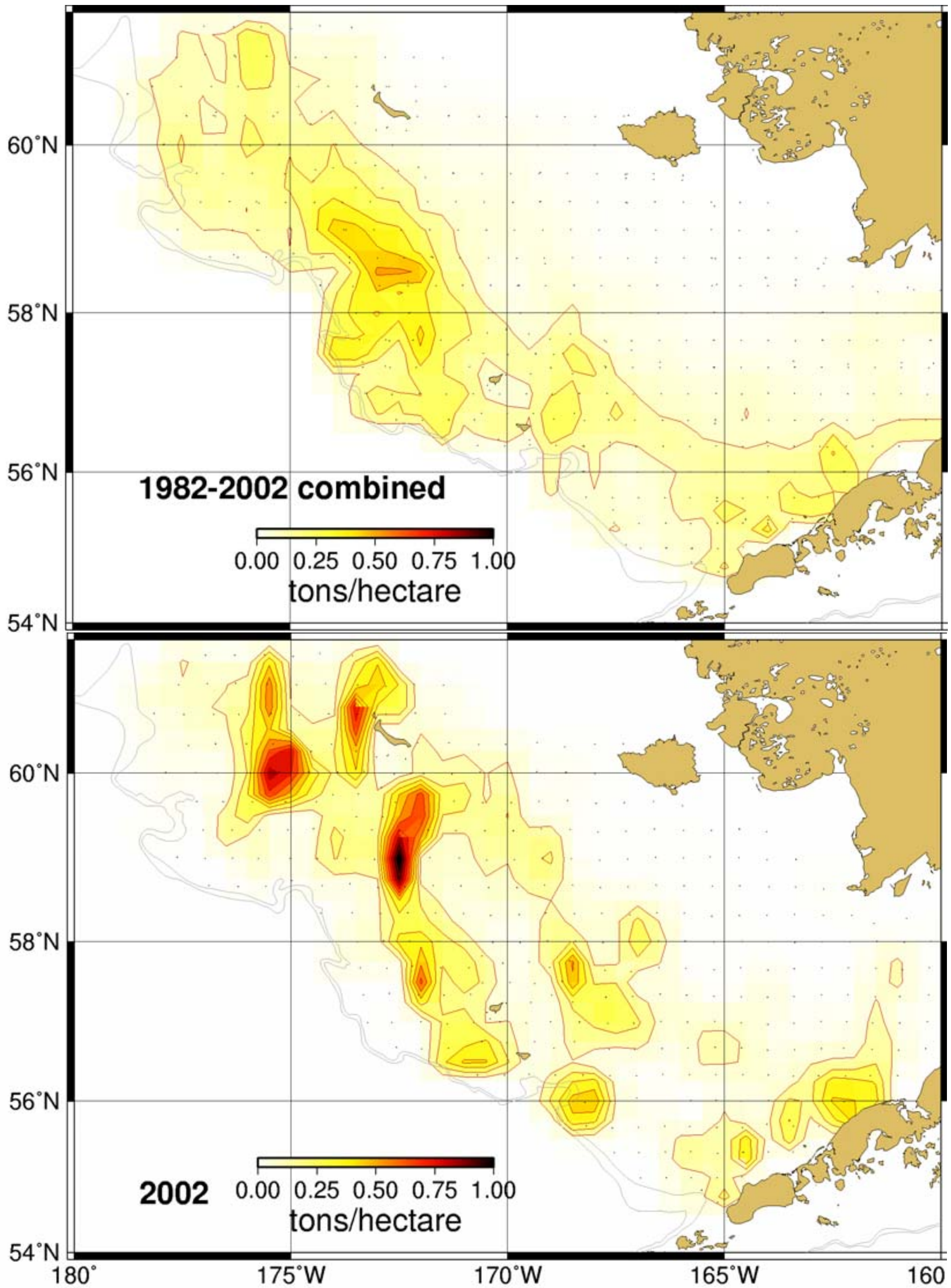



Figure 1.12. Maps showing the average walleye pollock catch-per-unit effort (1982-2002) compared to that observed during the 2002 NMFS EBS shelf bottom-trawl survey (bottom). Note that the average distribution plot contains CPUE values from the northwest portion that is not part of the "standard" survey area.

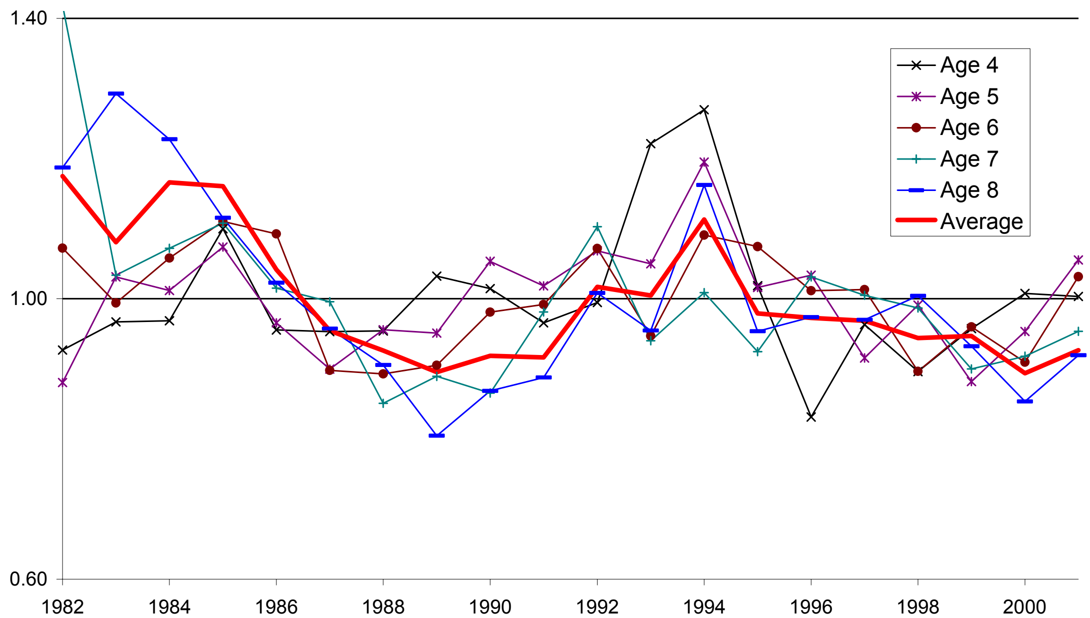



Figure 1.13. Trends in pollock average weights-at-age based on NMFS bottom trawl survey estimates, 1982-2001. Values are shown relative to their mean within each age or age group. Note that the length-weight relationship used here is constant, hence the differences are how average lengths-at-age vary over time in terms of weight.

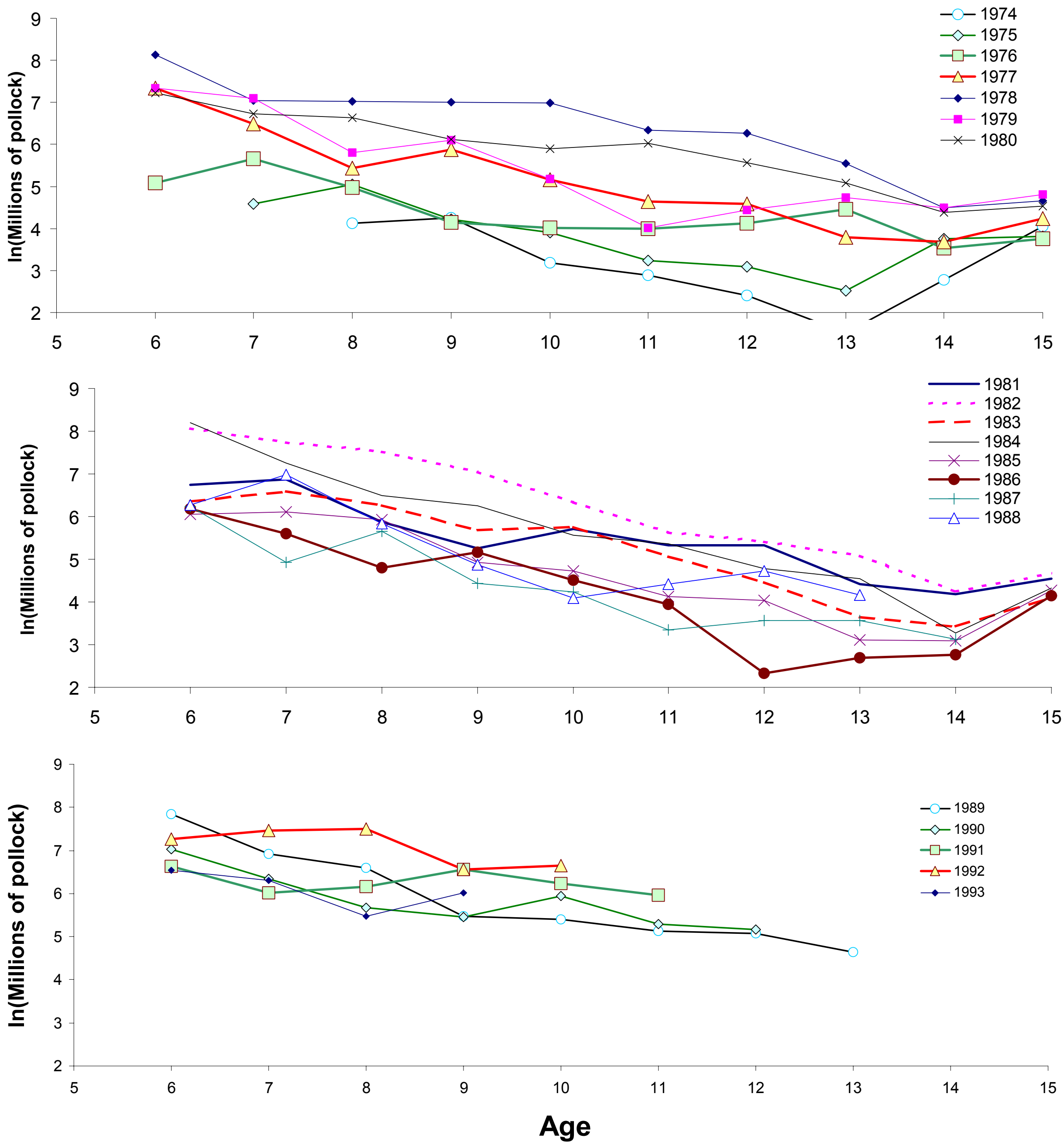



Figure 1.14. Log-abundance levels of individual EBS pollock cohorts (year classes) as estimated directly from the NMFS bottom-trawl surveys. Estimates at age 15 were omitted since they represent age 15 and older pollock.

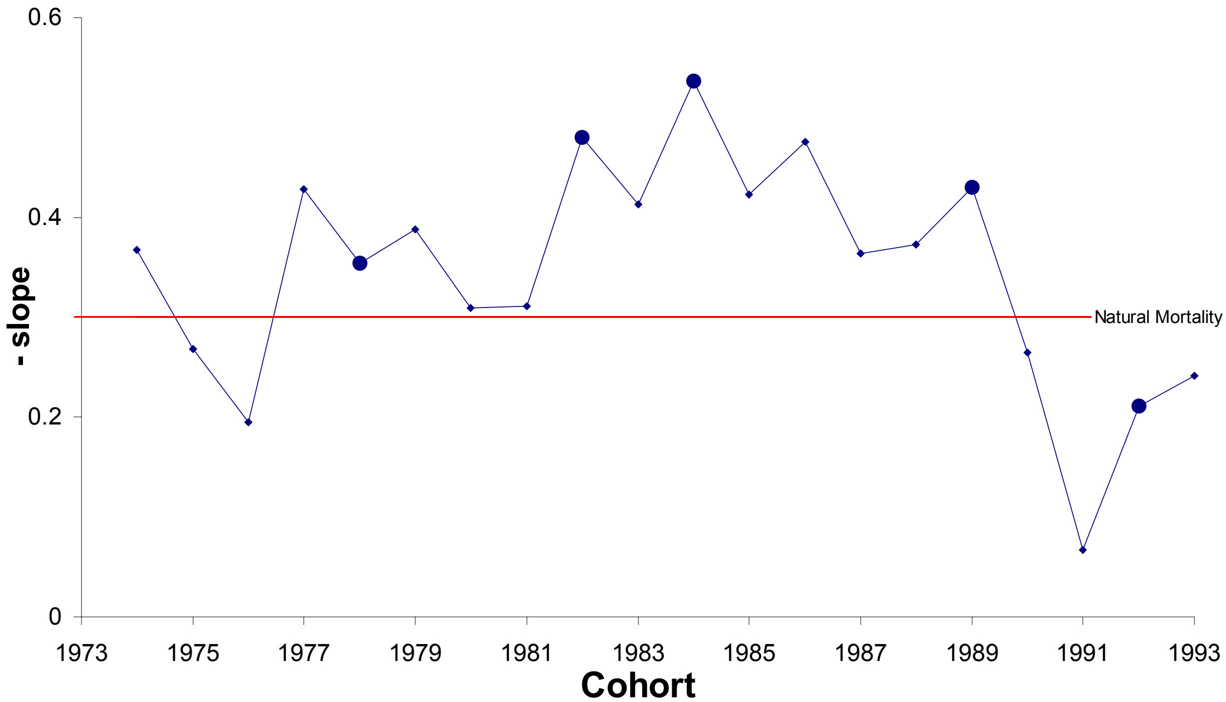



Figure 1.15. Negative slope estimates (as a proxy for total instantaneous mortality, Z) for 1974-1993 EBS pollock cohorts based on log-abundance levels as estimated directly from the NMFS bottom-trawl surveys. The assumed natural mortality rate for ages 3+ is shown as the single horizontal line. Year classes greater than average are indicated by the larger filled circles.

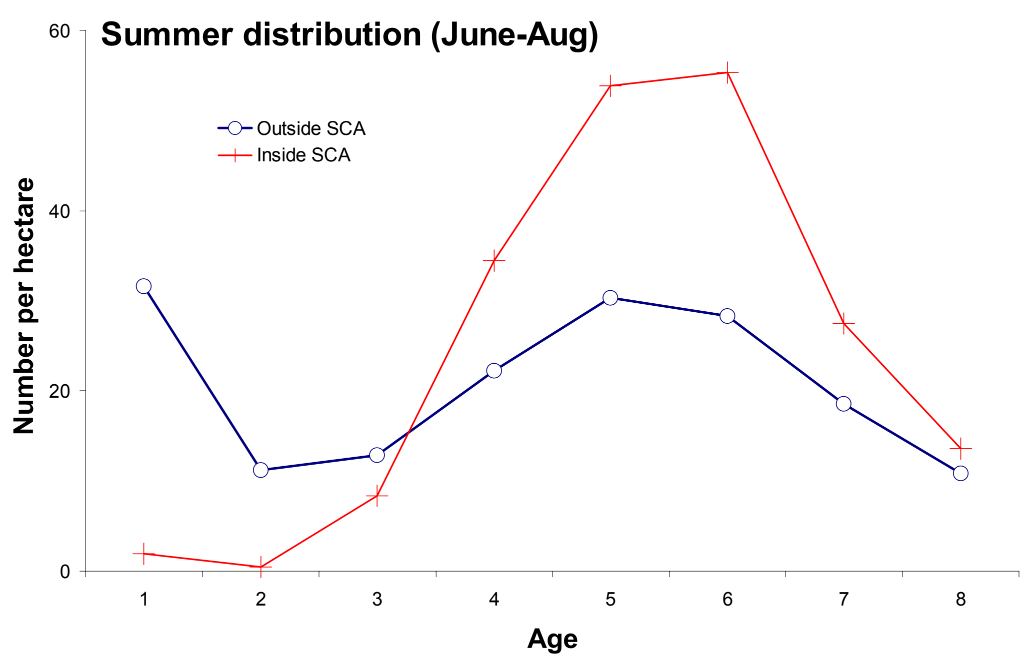



Figure 1.16. EBS pollock mean number per hectare by age based on tow-by-tow age-specific CPUE analyses of the NMFS bottom-trawl survey, 1982-1999.

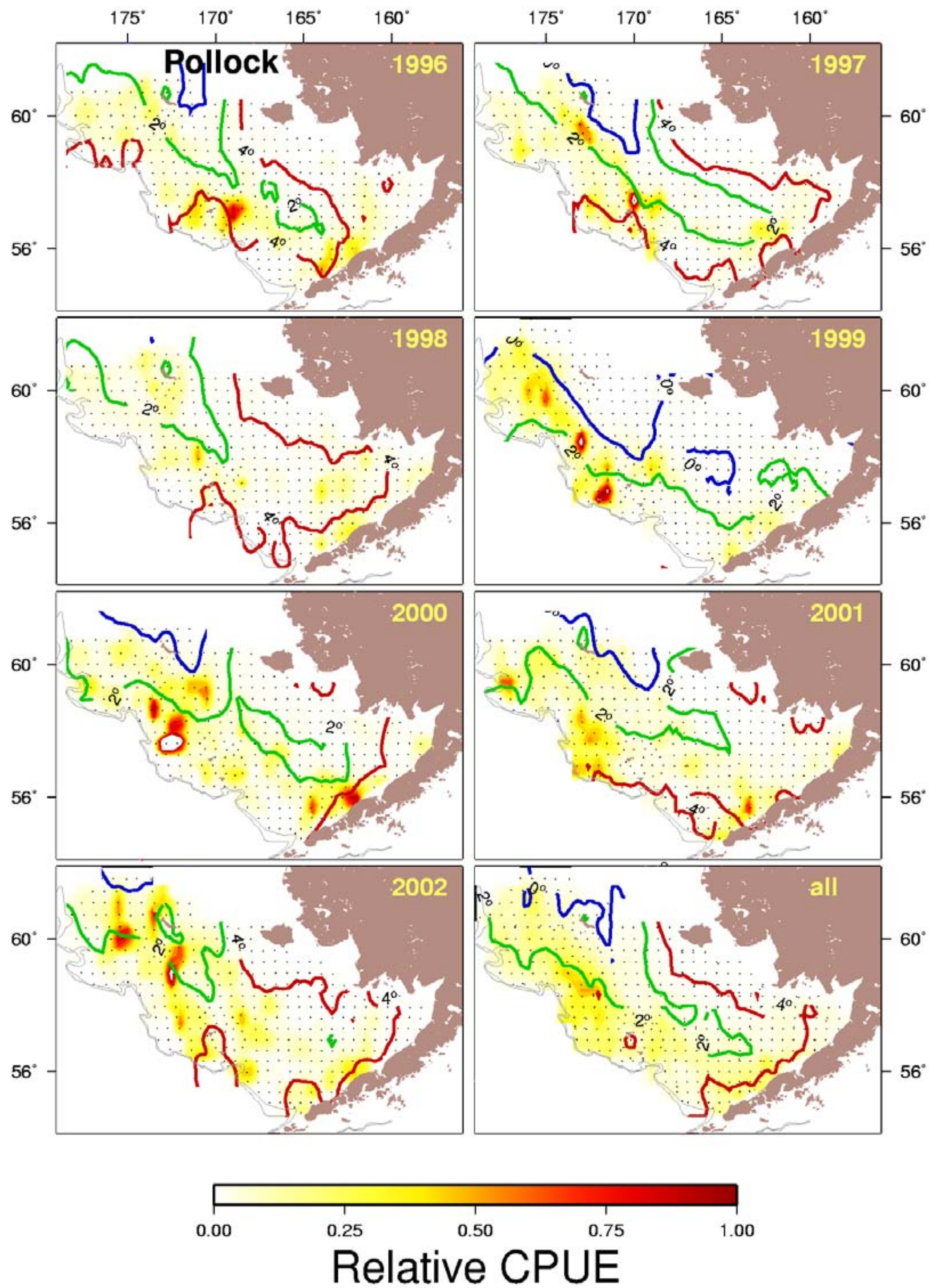



Figure 1.17. EBS pollock CPUE (shades kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius for 1996-2002. The average temperature and pollock density from 1982-2002 is shown in the lowest right panel.

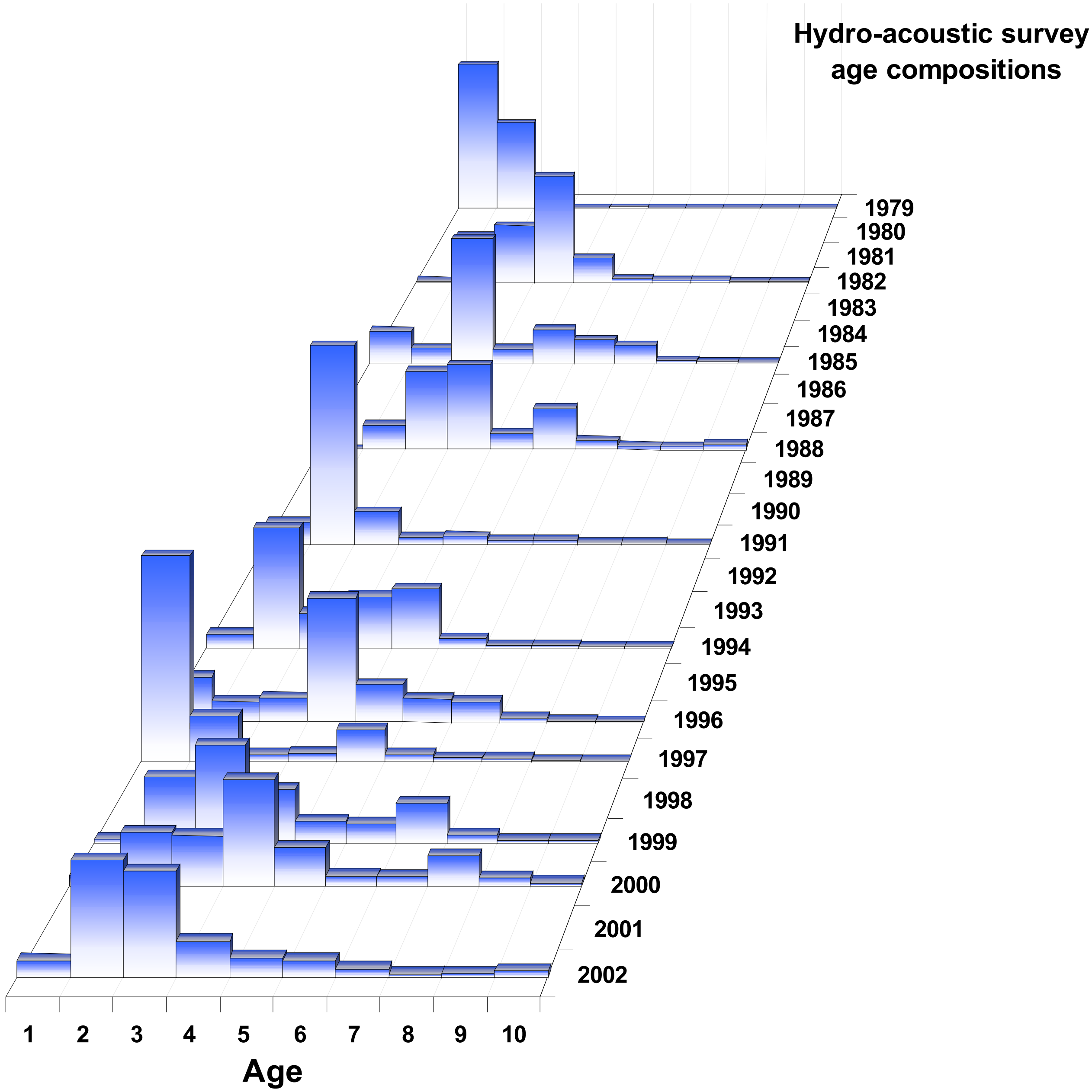



Figure 1.18. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-2000. Note: 2002 estimates are based on area-split bottom-trawl survey age-length key estimates and are preliminary—estimates based on age-determinations for the EIT survey will be completed in the coming year.

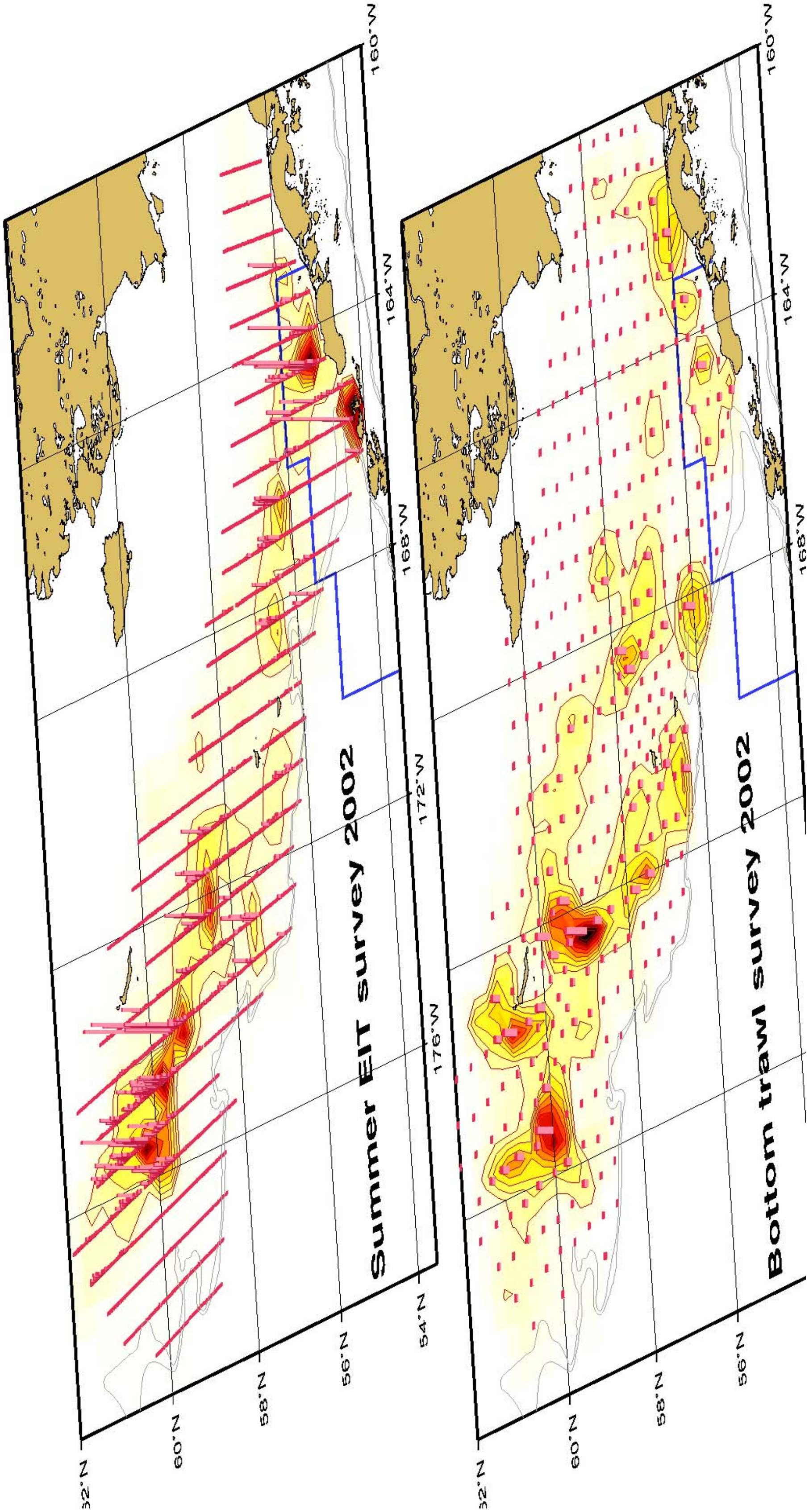



Figure 1.19. Map of the density of pollock observed during the EIT 2002 summer survey (top) and during the bottom trawl survey (bottom).

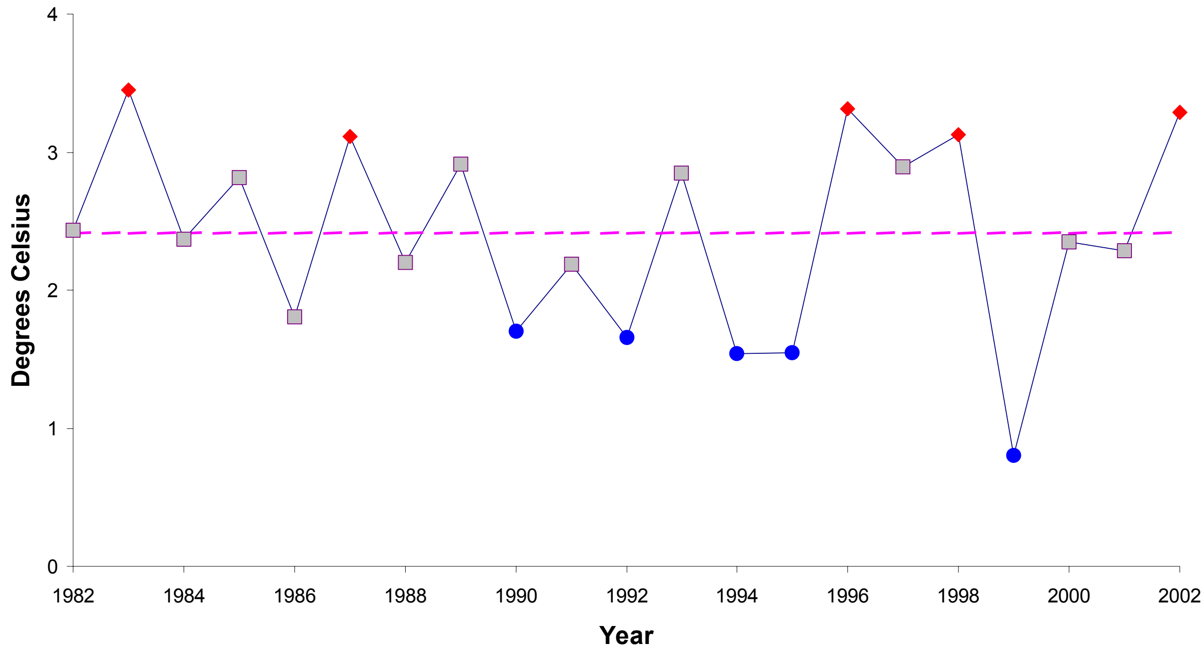



Figure 1.20. Mean summer bottom temperatures used to model bottom trawl survey pollock catchability, 1982-2002. (Note: these were normalized to have mean zero for use in the model).

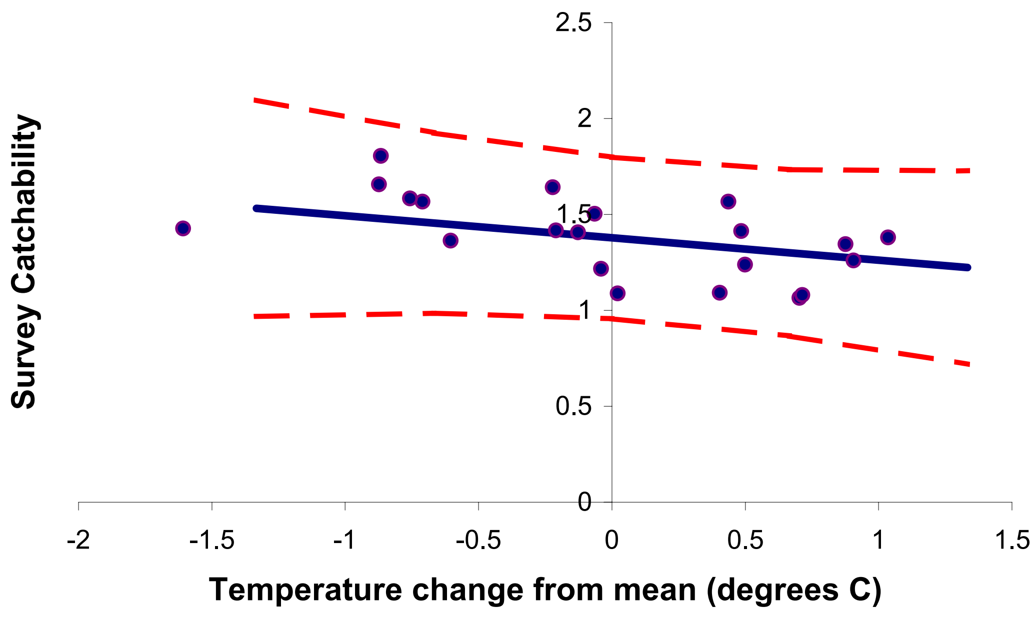



Figure 1.21. Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0) as under Model 4. Residuals relative to survey estimates are shown as points.

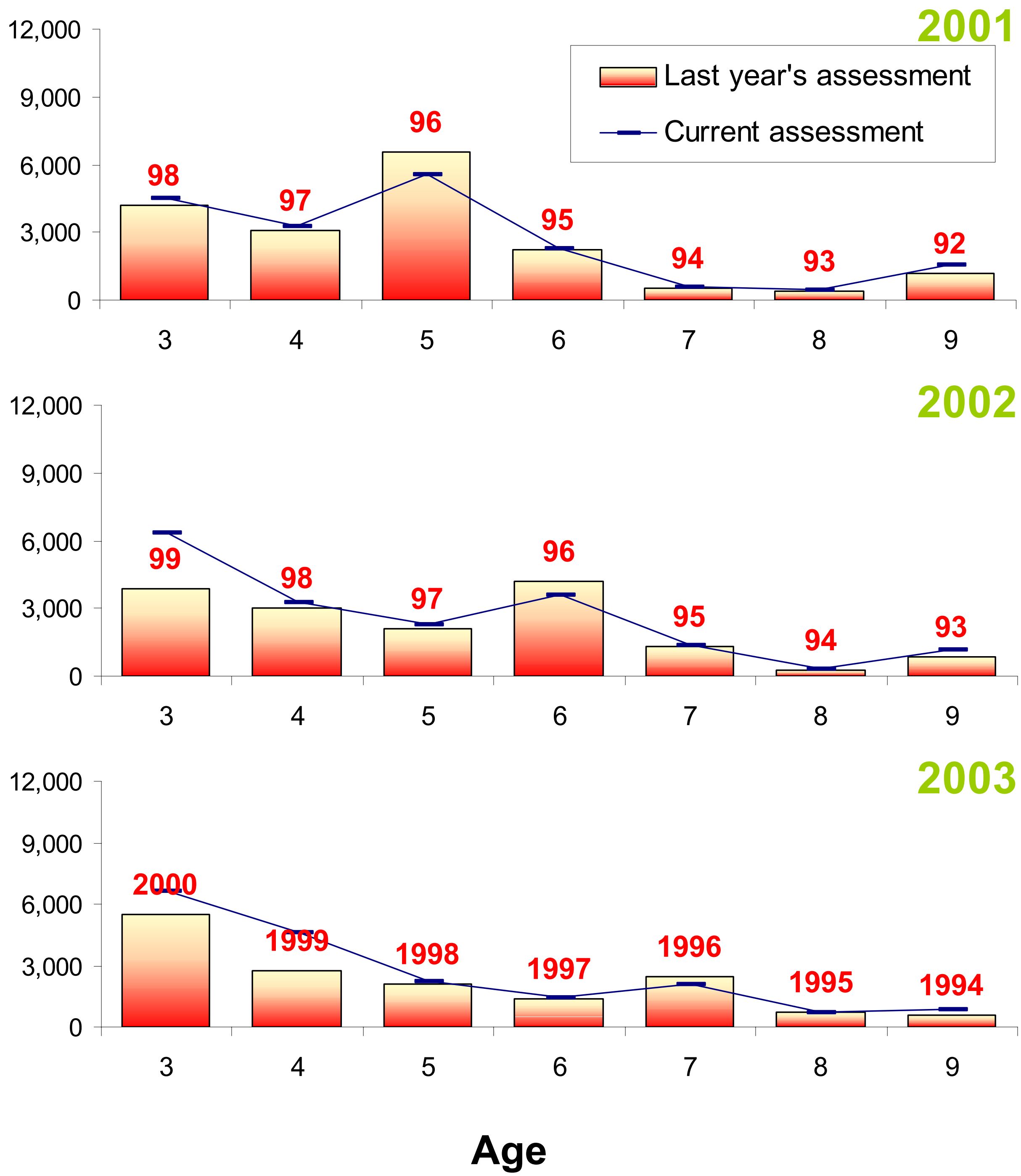



Figure 1.22. Projected EBS walleye pollock Model 1 population numbers at age compared with those presented in the last assessment (Model 1 from Ianelli *et al.*2001). Note that the "age 9" category represents all pollock age 9 and older.

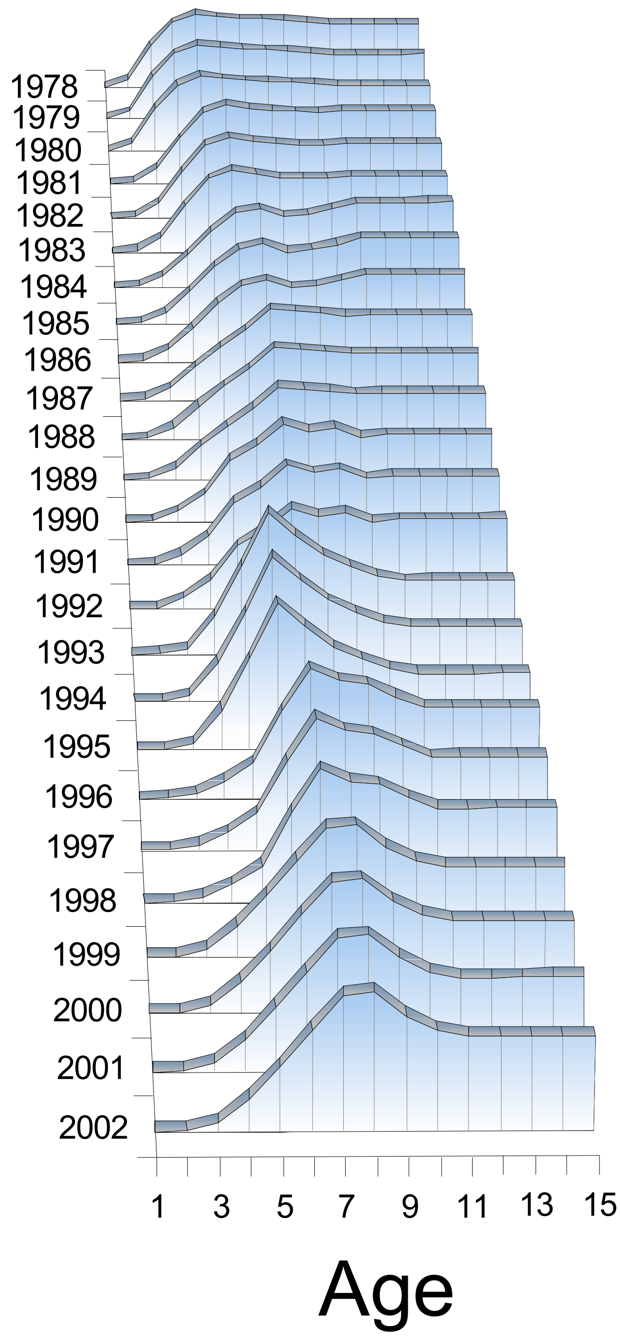



Figure 1.23. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-2002 estimated for Model 1.

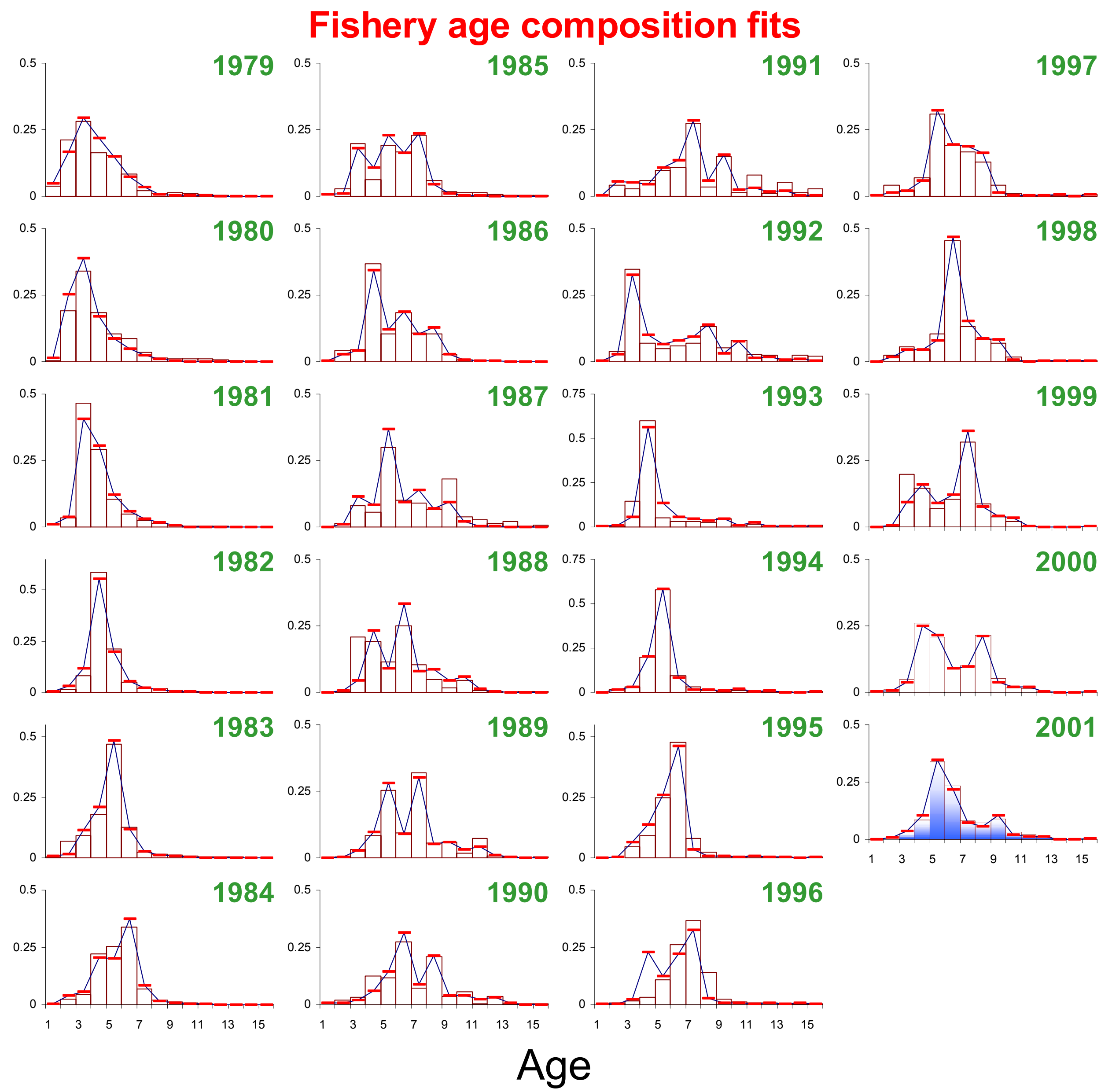



Figure 1.24. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1979-2001). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

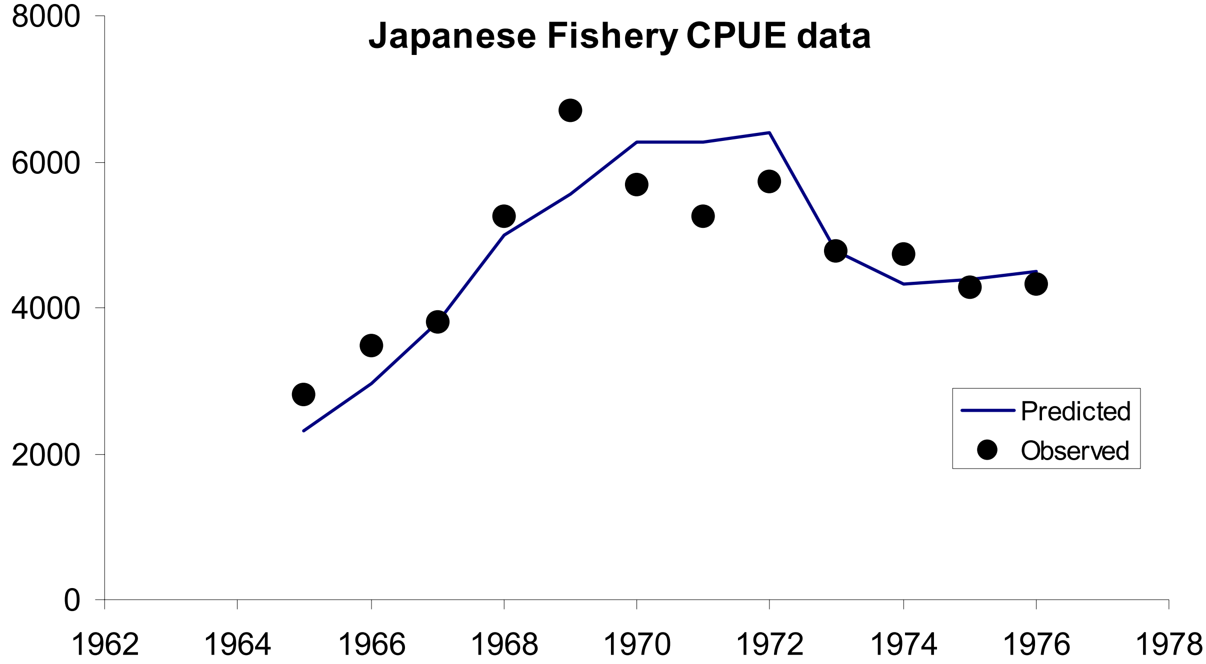



Figure 1.25. Model 1 fit to the EBS walleye pollock fishery CPUE data from Low and Ikeda (1980).

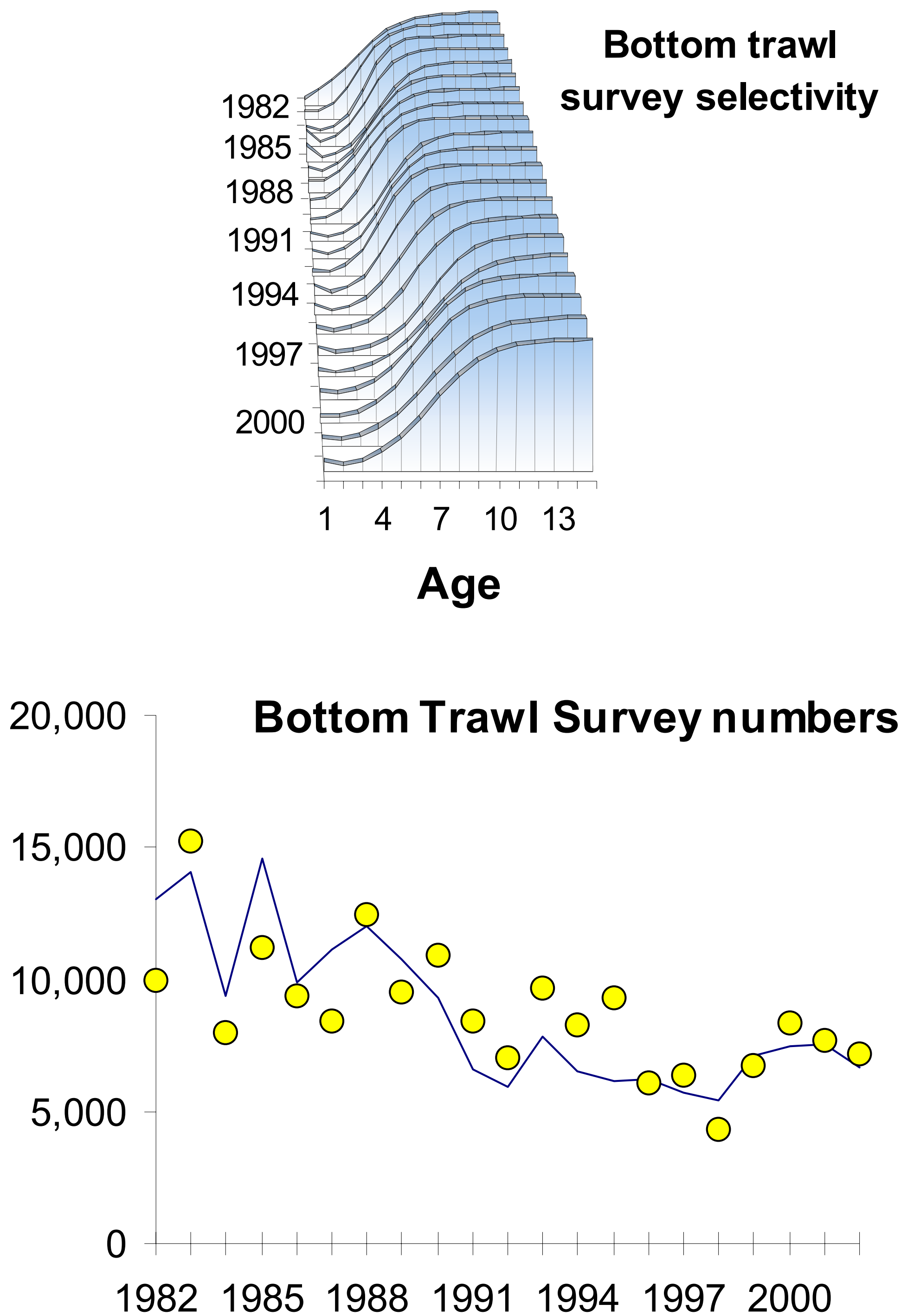



Figure 1.26. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS walleye pollock, Model 1.

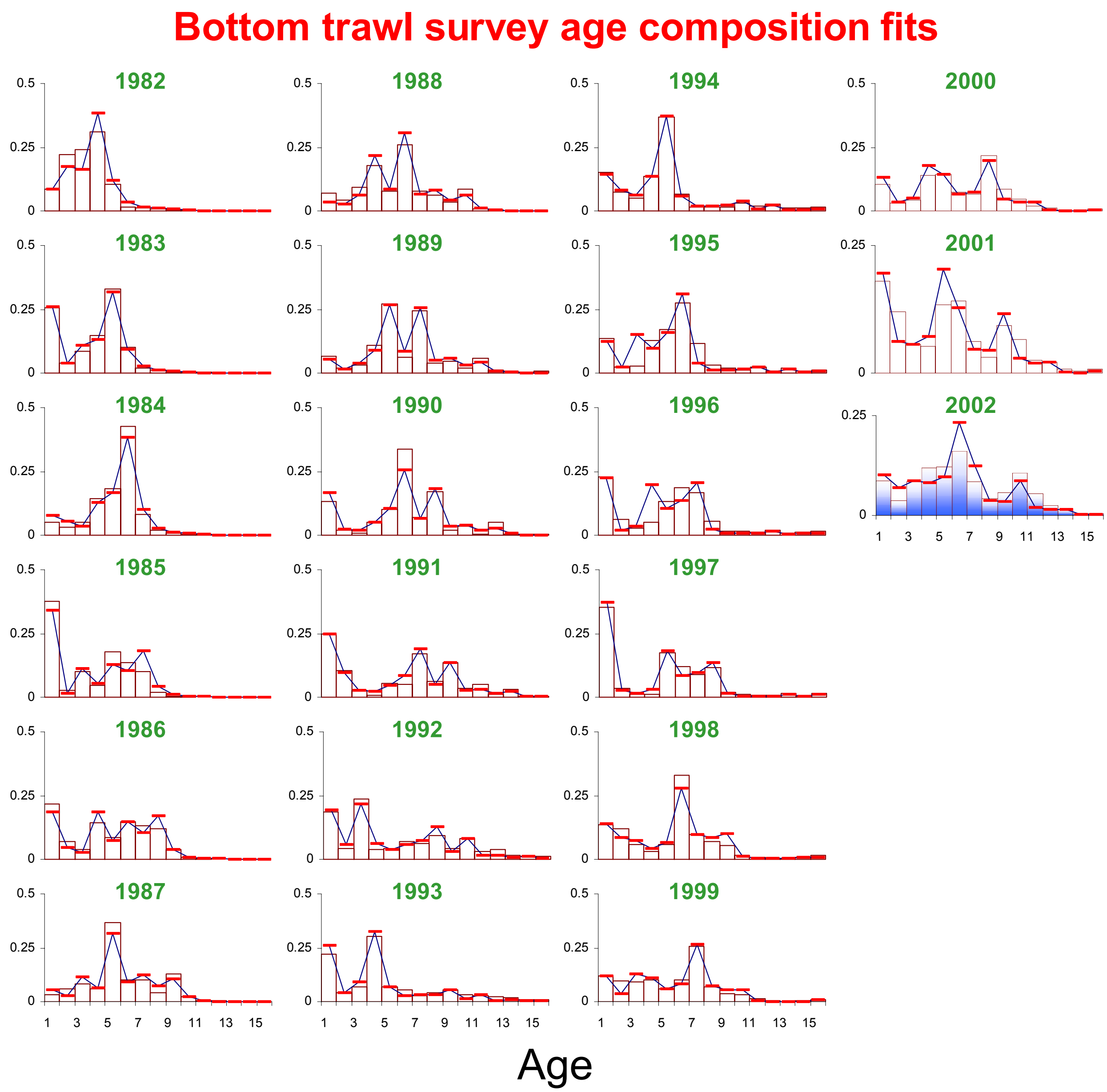



Figure 1.27. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded (2002).

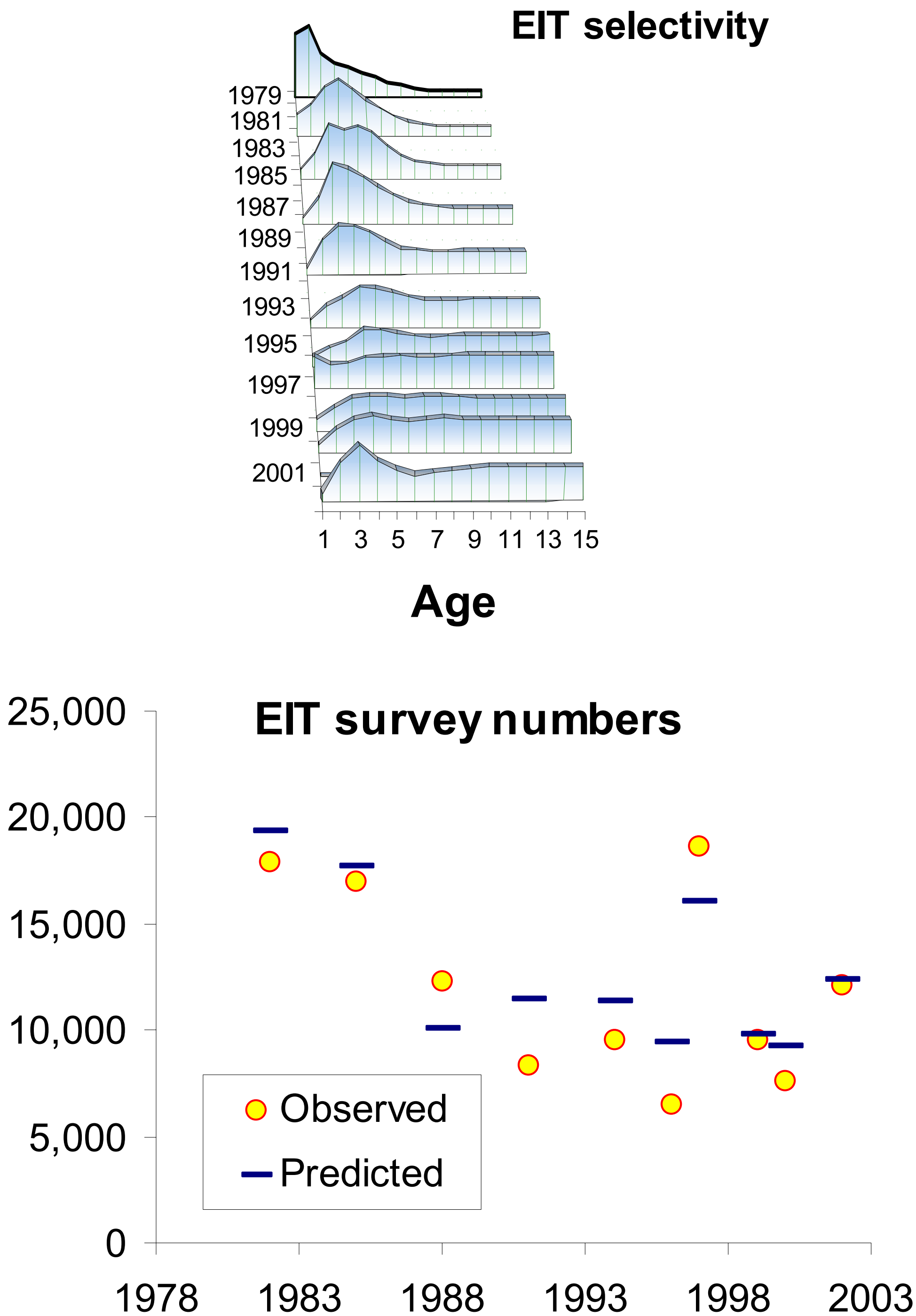



Figure 1.28. Model 1 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock. Note that the 1979 value (observed=115,424; predicted=48,071) are not plotted.

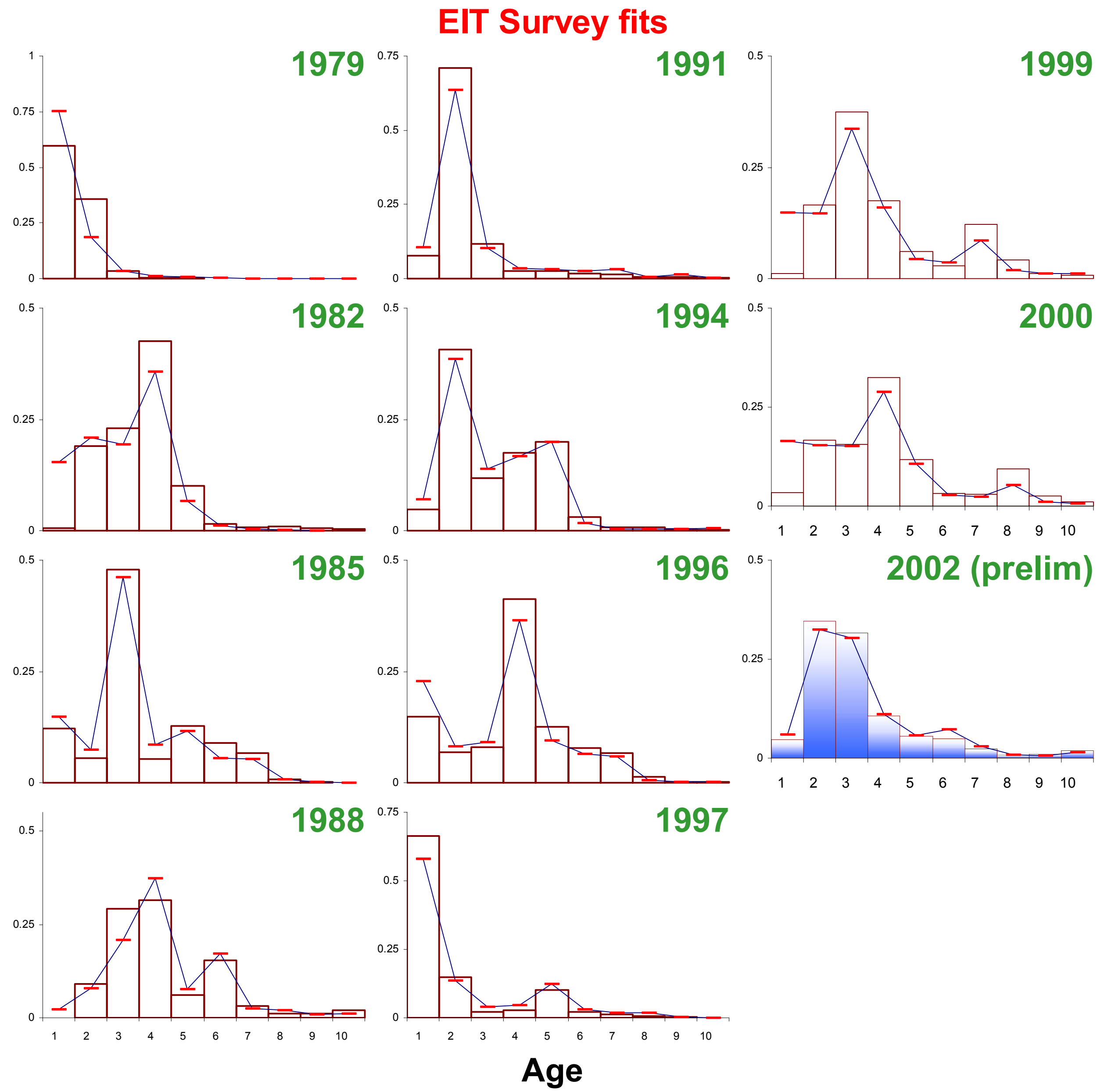



Figure 1.29. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data. Note that 2002 data are preliminary since they were computed using age-length keys from the 2002 bottom-trawl survey.

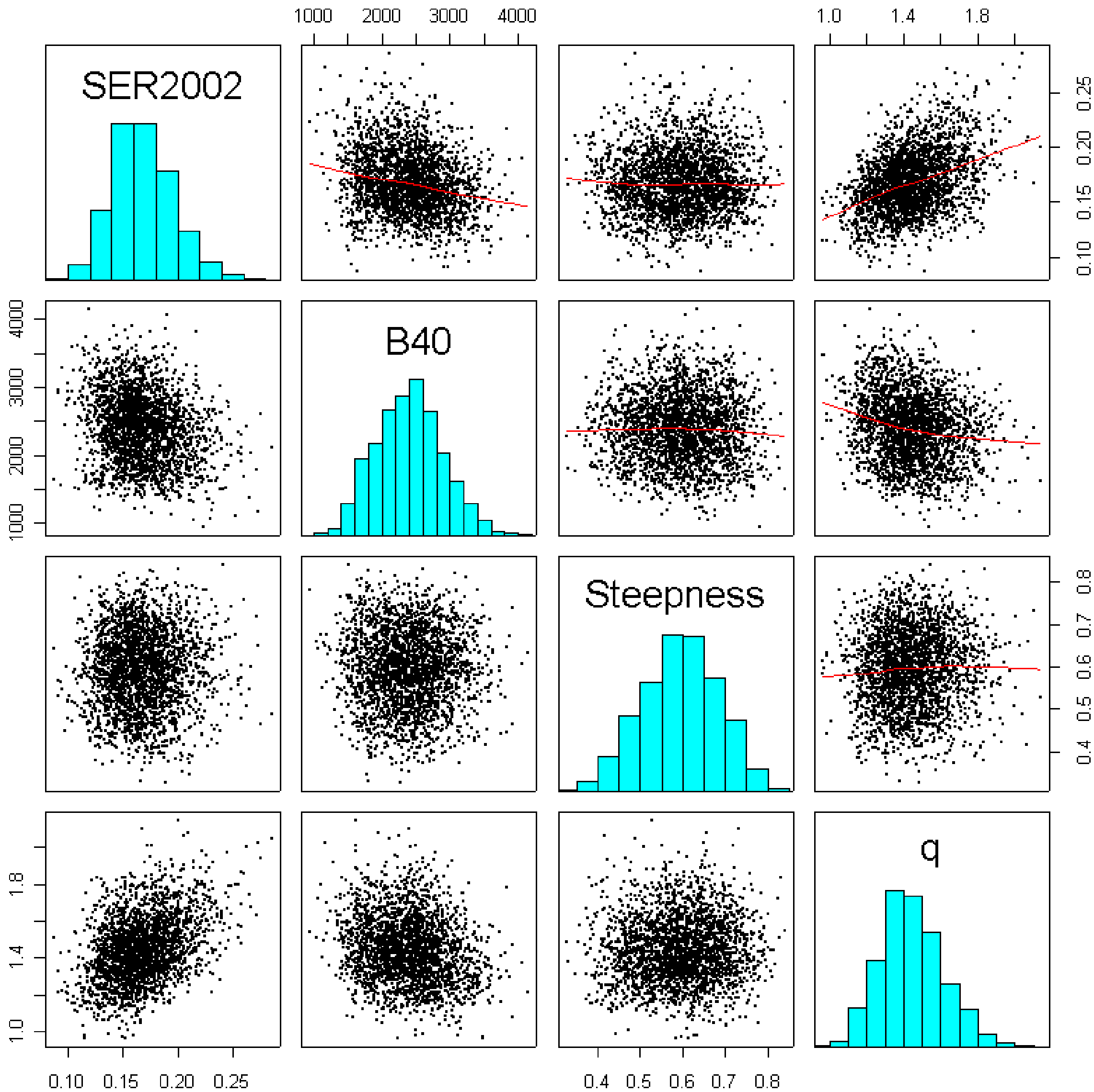



Figure 1.30. Pair-wise marginal plots of selected parameters of the joint posterior distribution based on a thinned MCMC chain used for integration. SER2002 is the estimate of spawning exploitation rate in 2002, B40 is the estimate of $B_{40\%}$, steepness is the critical stock-recruitment parameter related to the slope at the origin, and q is the combined catchability estimates from the EIT and bottom-trawl survey.

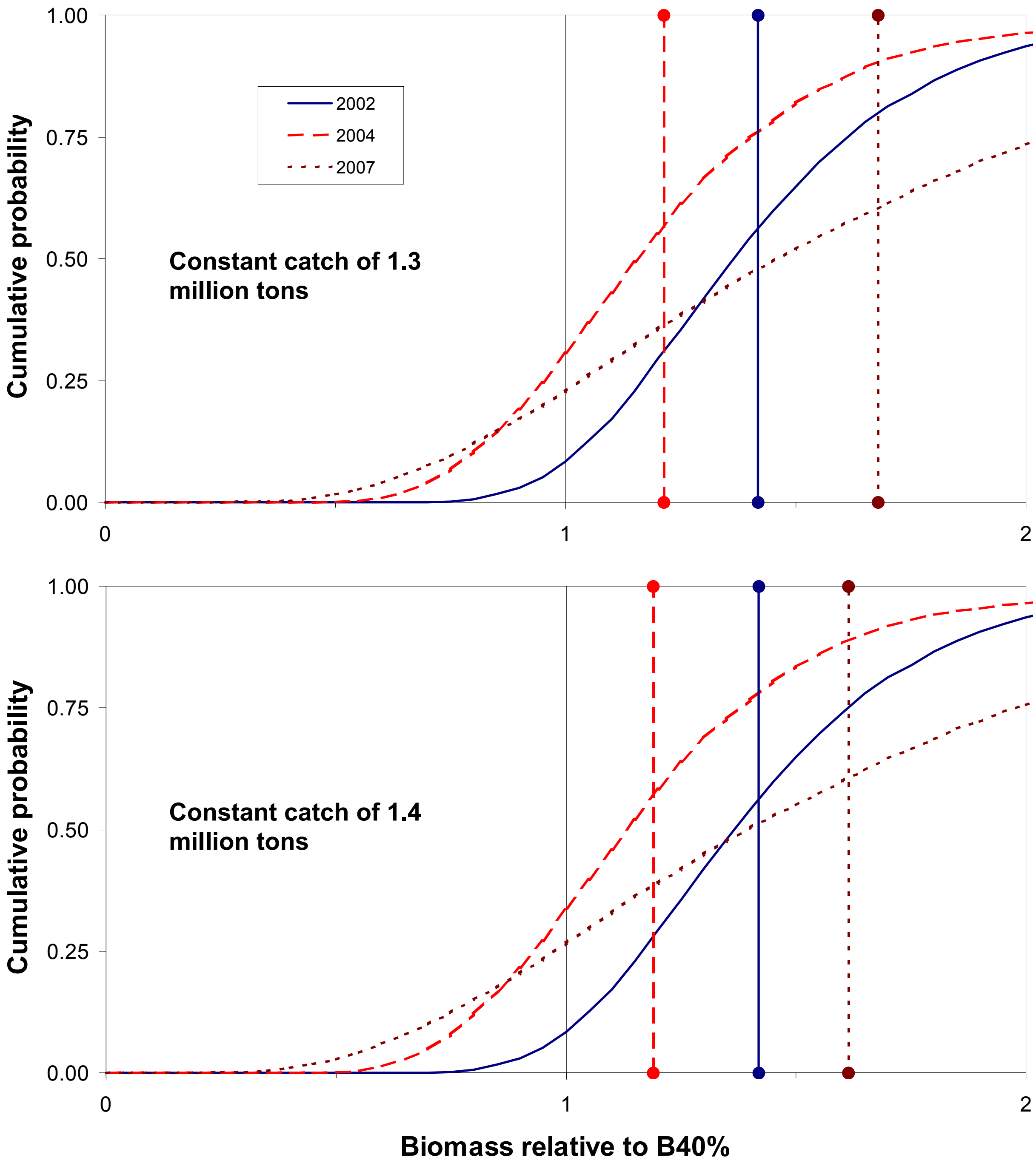



Figure 1.31. Cumulative probability that projected female spawning biomass levels will drop below $B_{40\%}$ based on a fixed constant catch levels of 1.3 (top) and 1.4 (bottom) million tons. Marginal distributions the full joint posterior distribution based on a thinned MCMC chain used for integration. Corresponding expected values (means) are shown by the vertical lines terminated with closed circles.

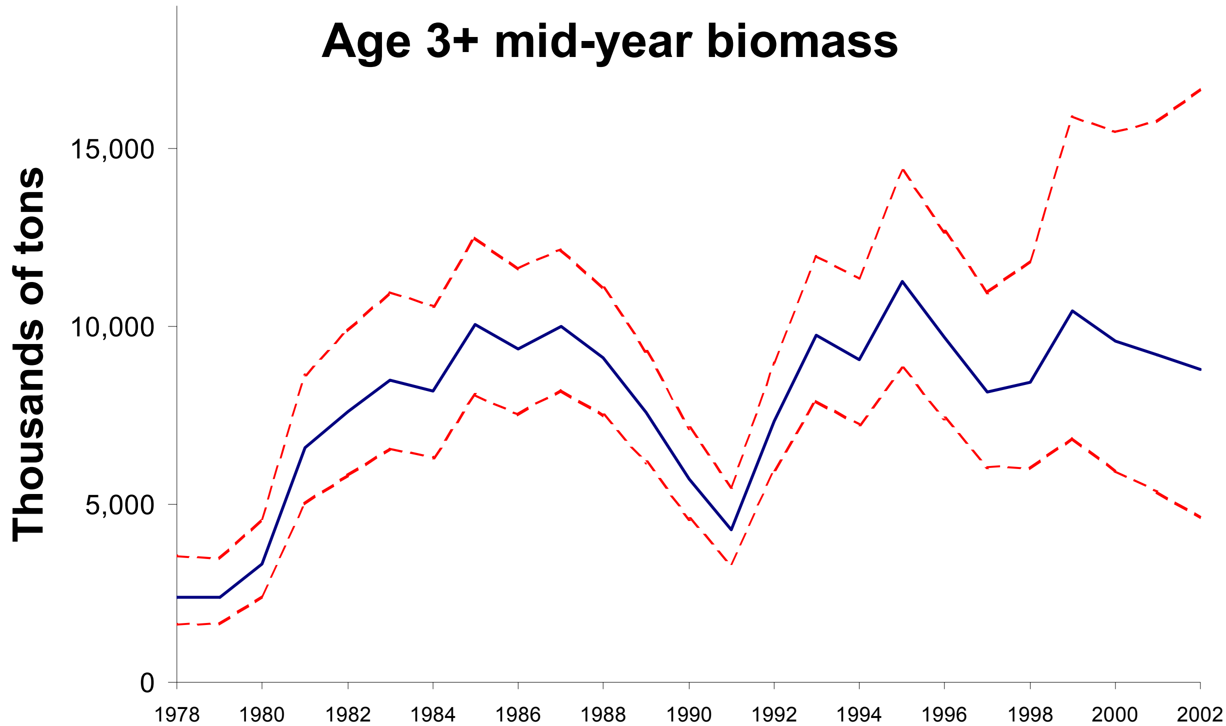



Figure 1.32. Estimated age 3+ EBS mid-year walleye pollock biomass under Model 1, 1978-2002. Approximate upper and lower 95% confidence limits are shown by dashed lines. Note: average fishery weights-at-age are applied to mid-year numbers-at-age to compute these values.

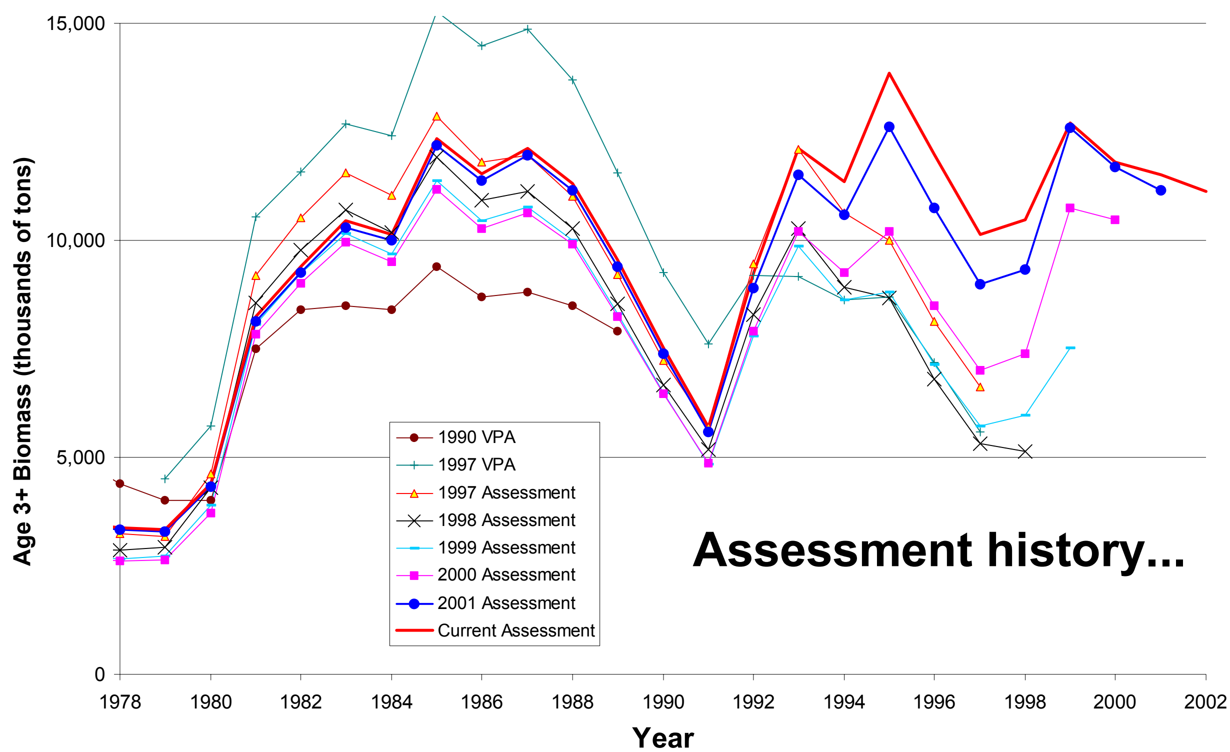



Figure 1.33. Comparison of the current assessment results with past assessments of begin-year EBS age-3+ pollock biomass, 1978-2002.

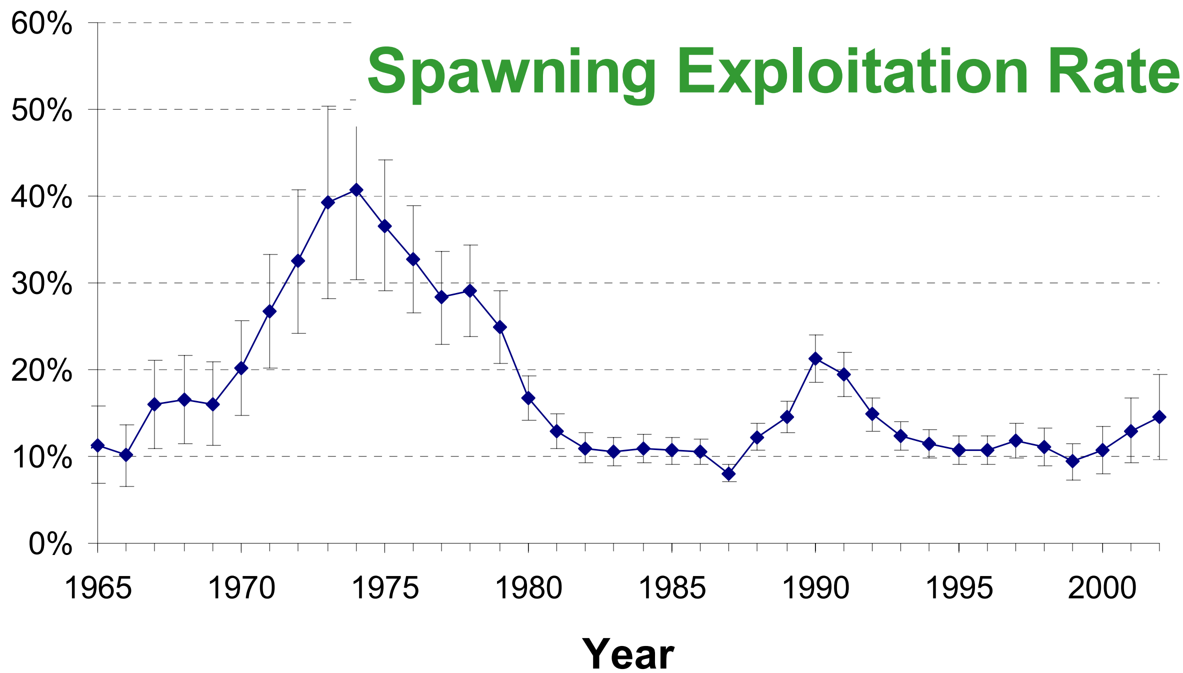



Figure 1.34. Estimated spawning exploitation rate (computed as the percent removals of spawning females each year) for EBS walleye pollock, Model 1. Error bars represent two standard deviations from the estimate.

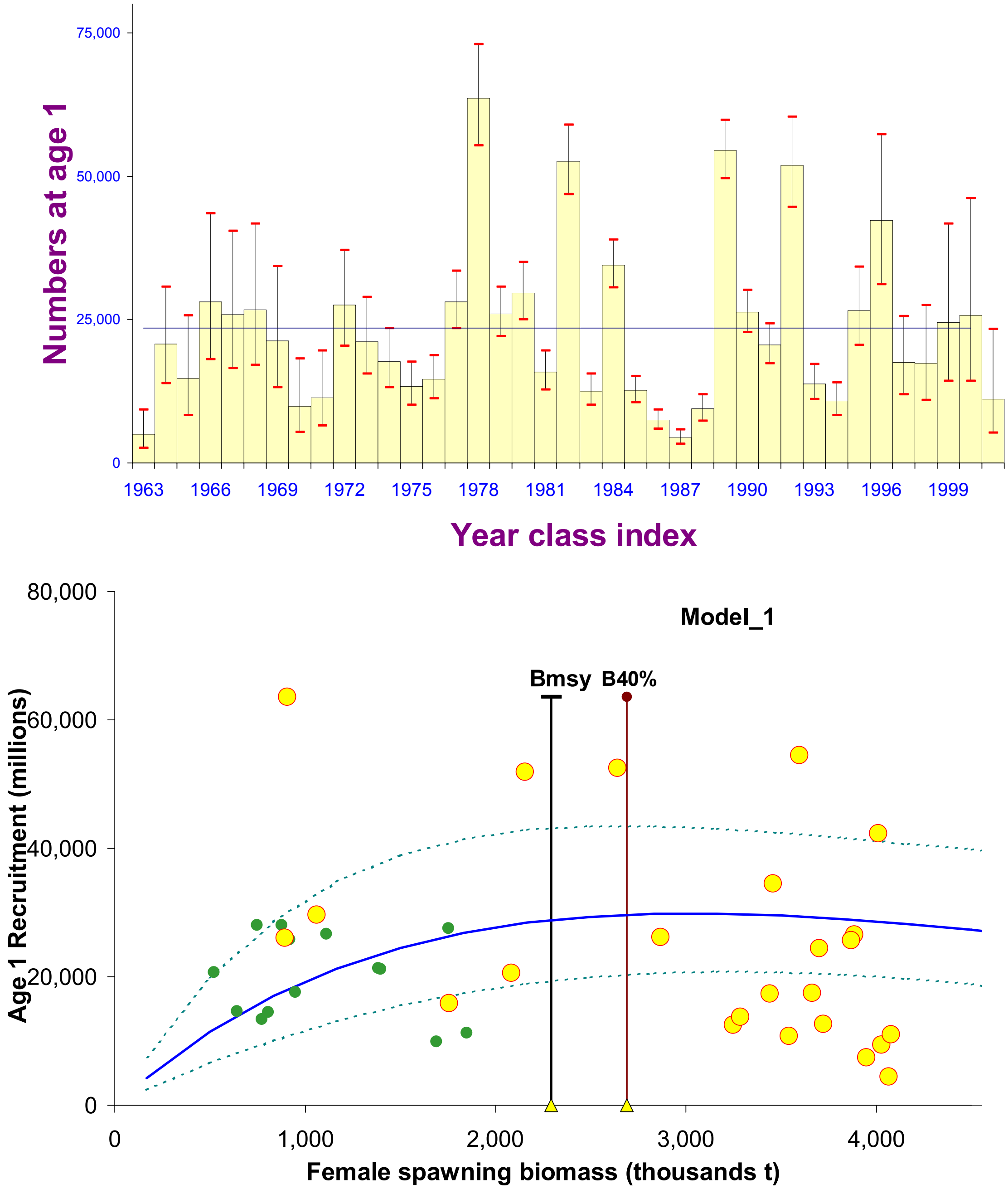
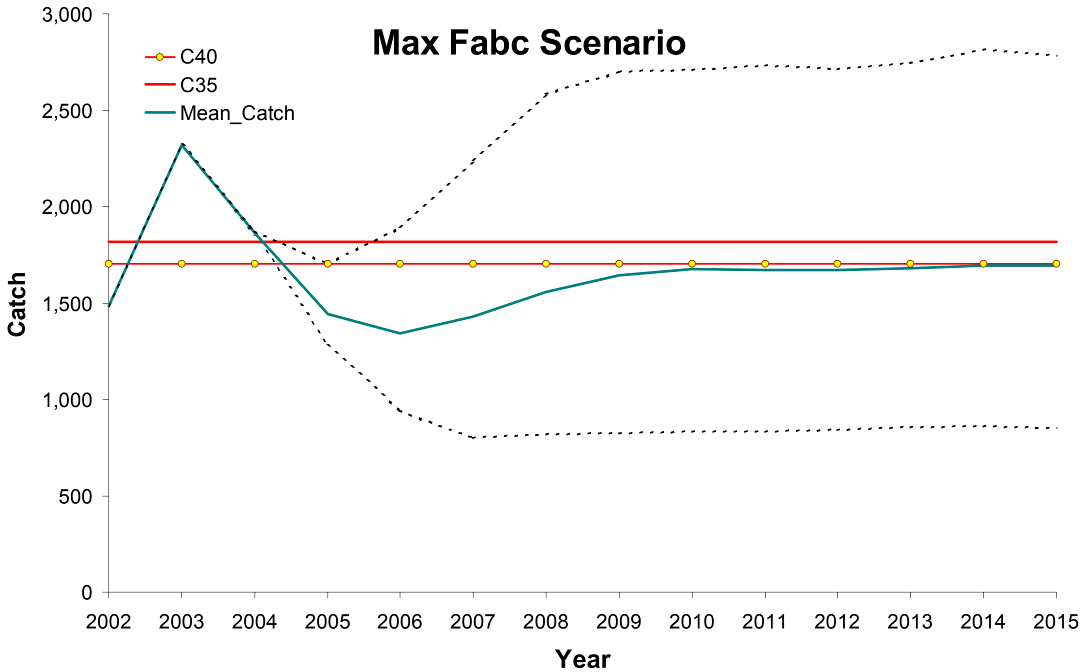



Figure 1.35. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate $B_{msy}$ and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with diagonal representing the replacement lines with no fishing. Dashed lines represent lower and upper 95% confidence limits about the curve.



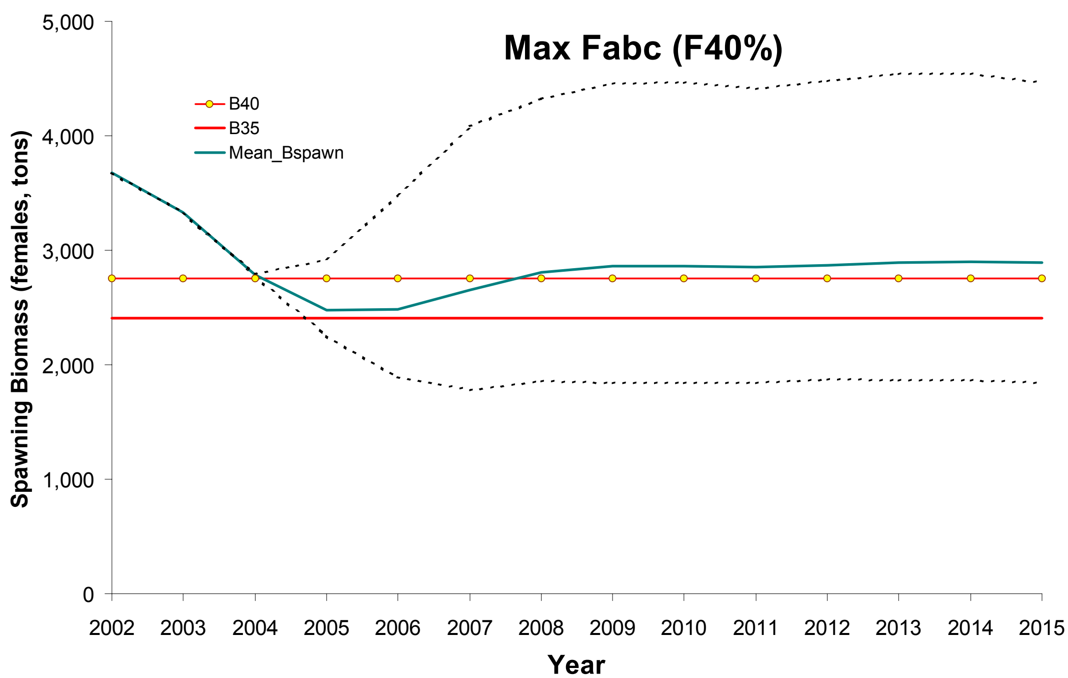




Figure 1.36. Projected EBS walleye pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2002. Future harvest rates follow the guidelines specified under Scenario 1, max $F_{ABC}$ assuming $F_{ABC} = F_{40\%}$.

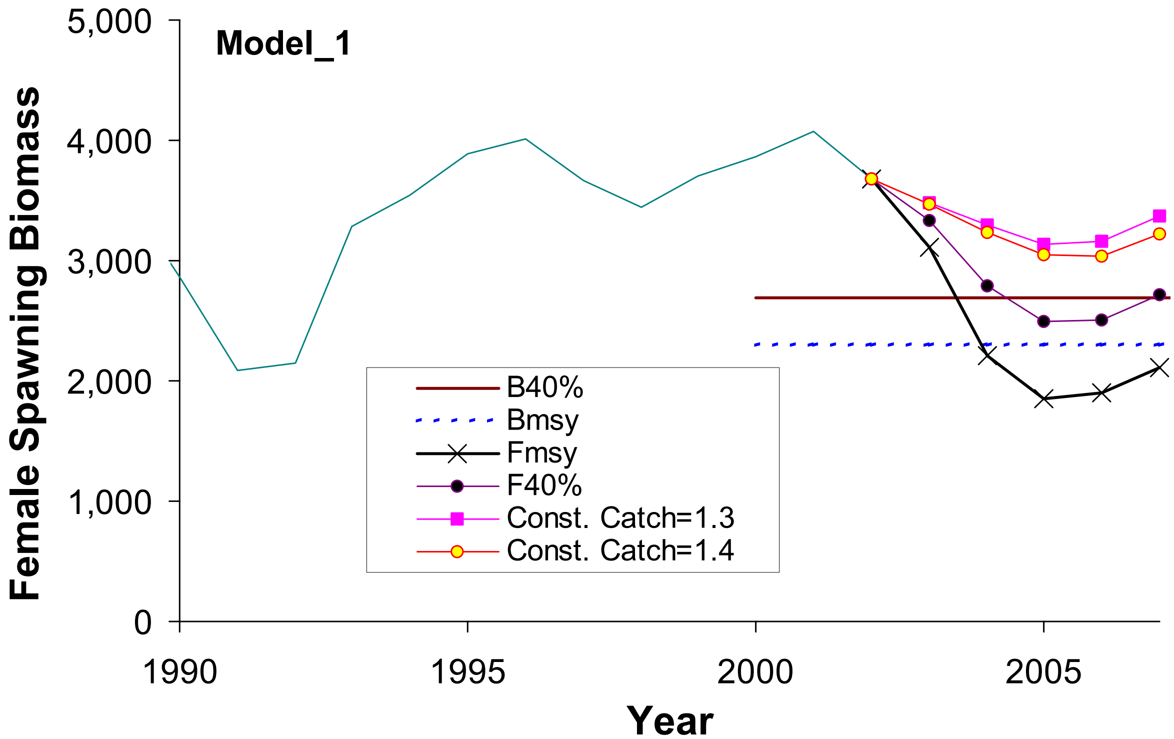
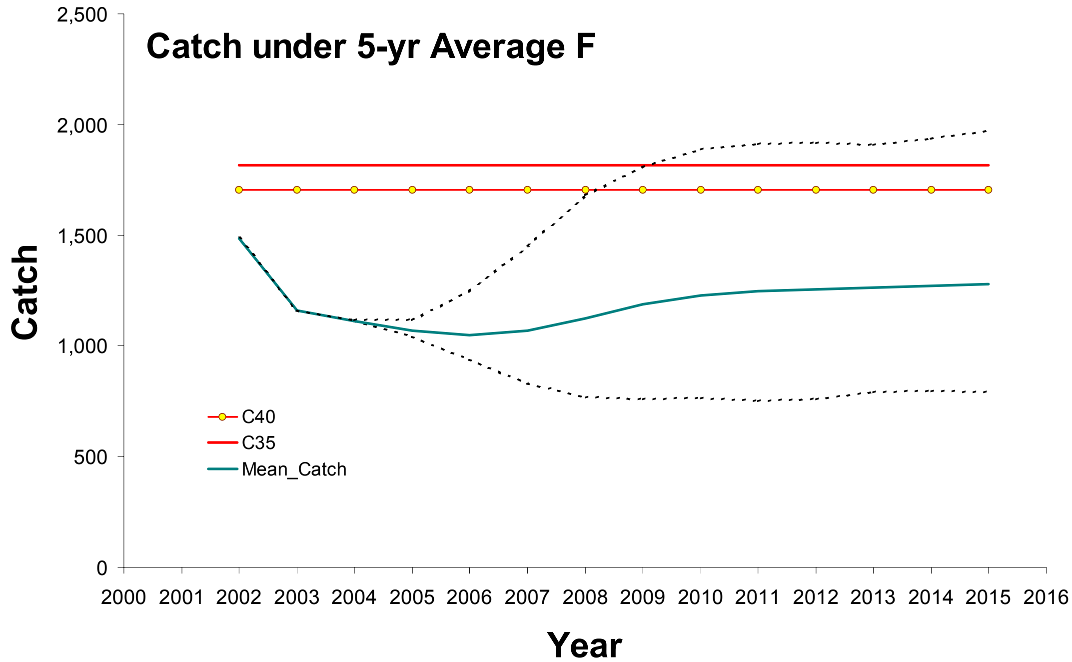



Figure 1.37. EBS walleye pollock female spawning biomass abundance trends, 1990-2007 as estimated by Model 1 and projections to 2007 at different catch strategies. Note that the $F_{msy}$ catch levels are unadjusted. Horizontal solid and dashed lines represent the $B_{msy}$, and $B_{40\%}$ levels, respectively.



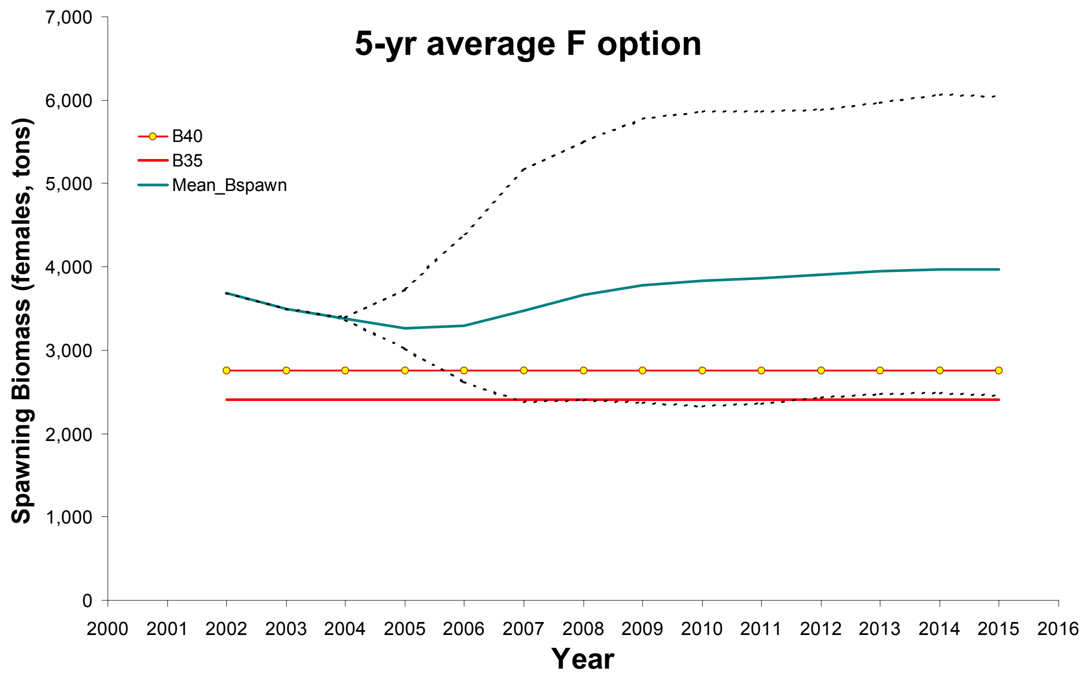




Figure 1.38. Projected EBS walleye pollock yield (top) and spawning biomass (bottom) under $F$ equal to the mean value from 1997-2001 relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1.

## 1.14. Model details

### 1.14.1. Model structure

We used an explicit age-structured model with the standard catch equation as the operational population dynamics model (e.g., Fournier and Archibald 1982, Hilborn and Walters 1992, Schnute and Richards 1995). Catch in numbers at age in year $t$ ($C_{a,t}$) and total catch biomass ($Y_t$) were

$$
\begin{aligned}
C_{t,a} &= \frac{F_{t,a}}{Z_{t,a}}\left(1-e^{-Z_{a,t}}\right)N_{t,a}, && 1 \le t \le T \quad 1 \le a \le A \\
N_{t+1,a+1} &= N_{t,a}e^{-Z_{t,a}} && 1 \le t \le T \quad 1 \le a < A \\
N_{t+1,A} &= N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}} && 1 \le t \le T \\
Z_{t,a} &= F_{t,a} + M_{t,a} \\
C_{t\cdot} &= \sum_{a=1}^{A} C_{t,a} \\
p_{t,a} &= C_{t,a} / C_{t\cdot} \\
Y_t &= \sum_{a=1}^{A} w_a C_{t,a} \text{ ,and}
\end{aligned}
$$

where

| | |
|---|---|
| $T$ | is the number of years, |
| $A$ | is the number of age classes in the population, |
| $N_{t,a}$ | is the number of fish age $a$ in year $t$, |
| $C_{t,a}$ | is the catch of age class $a$ in year $t$, |
| $p_{t,a}$ | is the proportion of the total catch in year $t$, that is in age class $a$, |
| $C_{t\cdot}$ | is the total catch in year $t$, |
| $w_a$ | is the mean body weight (kg) of fish in age class $a$, |
| $Y_{t\cdot}$ | is the total yield biomass in year $t$, |
| $F_{t,a}$ | is the instantantaneous fishing mortality for age class $a$, in year $t$, |
| $M_{ta}$ | is the instantantaneous natural mortality in year $t$ for age class $a$, and |
| $Z_{ta}$ | is the instantantaneous total mortality for age class $a$, in year $t$. |

We reduced the freedom of the parameters listed above by restricting the variation in the fishing mortality rates ($F_{t,a}$) by assuming that

$$
\begin{aligned}
F_{t,a} &= s_{t,a}\mu^f \exp\left(\varepsilon_t\right) && \varepsilon_t \sim N\left(0,\sigma_E^2\right) \\
s_{t+1,a} &= s_{t,a}\exp\left(\gamma_{t,a}\right), && \gamma_{t,a} \sim N\left(0,\sigma_s^2\right)
\end{aligned}
$$

where

| | |
|---|---|
| $s_{t,a}$ | is the selectivity for age class $a$ in year $t$, and |

$\mu^F$ is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term ($\sigma_s^2$) to allow selectivity to change slowly over time–thus improving our ability to estimate the $\gamma_{t,a}$. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., $\sigma_E^2$) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model "selectivity" of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise). The magnitude of these changes is determined by the prior variances as presented above.

One form used to model bottom-trawl survey selectivity (used in Models 1, 3-7) is to have an asymptotic yet retain the properties desired for the characteristics of this gear. Namely, that the function should allow for flexibility in selecting age 1 pollock. Additionally, time-varying shifts should be allowed. The new functional form of this selectivity is:

$$
\begin{aligned}
s_{t,a} &= \left[1 + e^{-\alpha_t(a-\beta_t)}\right]^{-1}, \quad a > 1 \\
s_{t,a} &= \mu_s e^{\delta_t^\mu}, \qquad\qquad\qquad a = 1 \\
\alpha_t &= \bar{\alpha} e^{\delta_t^\alpha} \\
\beta_t &= \bar{\beta} e^{\delta_t^\beta}
\end{aligned}
$$

where the parameters of the selectivity function follow a random walk process as in Dorn et al. (2000):

$$
\begin{aligned}
\delta_t^\mu - \delta_{t+1}^\mu &\sim N\left(0, \sigma_{\delta^\mu}^2\right) \\
\delta_t^\alpha - \delta_{t+1}^\alpha &\sim N\left(0, \sigma_{\delta^\alpha}^2\right). \\
\delta_t^\beta - \delta_{t+1}^\beta &\sim N\left(0, \sigma_{\delta^\beta}^2\right)
\end{aligned}
$$

The parameters to be estimated in this part of the model are thus the $\bar{\alpha}, \bar{\beta}, \delta_t^\mu, \delta_t^\alpha, \text{and } \delta_t^\beta$ for $t$=1982, 1983,…2002. The variance terms for these parameters were specified to be 0.04.

In the SAM analyses, recruitment ($R_t$) represents numbers of age-1 individuals modeled as a stochastic function of spawning stock biomass. A further modification made in Ianelli et al. (1998) was to have an environmental component to account for the differential survival attributed to larval drift (e.g., Wespestad et al. 2000). ($\kappa_t$):

$$
R_t = f\left(B_{t-1}\right) e^{\kappa_t + \tau_t}, \qquad \tau_t \sim \mathrm{N}\left(0, \sigma_R^2\right)
$$

with mature spawning biomass during year $t$ was defined as:

$$
B_t = \sum_{a=1}^{15} w_a \phi_a N_{at}
$$

and $\phi_a$ , the proportion of mature females at age, was the same as that presented in Wespestad (1995).

The environmental component is based on hypotheses about the relationship between surface advection during the post-spawning period (pollock egg and larval stages) and pollock survival. Wespestad et al. (2000) found that during years when the surface currents tended north-north westward along the shelf that year-class strength was improved compared to years when currents were more easterly. They used the OSCURS model to simulate drift. In a subsequent analyses (Ianelli et al. 1998) their analysis was extended to apply within a stock assessment model context. The procedure is briefly outlined as follows:

1) run the OSCURS model for 90 days in each year starting at 165W and 55.5N storing the daily locations;

2) compute the average location of the simulated drifter over the 90 day period within each year using the GMT program (Wessel and Smith 1991) ***`fitcircle`***.

3) plot these points and create a geographic grid (**A**) centered such that it covers all mean values over all years,

4) create an indicator matrix ($\Psi$) dimensioned such that the rows correspond to the number of years needed for the model (here 1964 – 1997) and the columns represent either the row or column index of the geographic grid. For example, say the average location of a drifter in 1980 fell within the bounds of the geographic grid cell represented by the 2nd column and 4th row, then the indicator matrix would have 2 and 4 as entries for the row corresponding to 1980.

Submit the indicator matrix as data to be read in to the model so that the values of the geographic grid matrix can be estimated where:

$$\kappa_t = A\left(\Psi_{t,1}, \Psi_{t,2}\right), \qquad \kappa_t \sim \mathrm{N}\left(0, \sigma_\kappa^2\right) \ .$$

The idea is simply that there are "good" circulation patterns and "bad" circulation patterns within the first few months after spawning.

### *Reparameterization of the stock-recruitment function*

This year we implemented a reparameterized form for the stock-recruitment relationship as by Francis (1992). For the Beverton-Holt form we have:

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1}e^{\varepsilon_t}}{\alpha + \beta B_{t-1}}$$

where

$R_t$ is recruitment at age 1 in year *t,*

$B_t$ is the biomass of mature spawning females in year *t,*

$\varepsilon_t$ is the "recruitment anomaly" for year *t*,

$\alpha$, $\beta$ are stock-recruitment function parameters.

Values for the stock-recruitment function parameters $\alpha$ and $\beta$ are calculated from the values of $R_0$ (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (*h*). The "steepness" is the fraction of $R_0$ to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$
$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawner biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of $R_0$.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawners (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of *h* = 0.9 implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level. Steepness of 0.7 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). The same prior distribution for steepness based on a beta distribution as in Ianelli et al. (2001) and is shown in Fig. 1.39.

To have the critical value for the stock-recruitment function (steepness, *h*) on the same scale for the Ricker model, we begin with the parameterization of Kimura (1990):

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1} e^{a\left(1-\frac{B_{t-1}}{\varphi_0 R_0}\right)}}{\varphi_0}.$$

It can be shown that the Ricker parameter *a* maps to steepness as:

$$h = \frac{e^a}{e^a + 4}$$

so that the prior used on *h* can be implemented in both the Ricker and Beverton-Holt stock-recruitment forms. Here the term $\varphi_0$ represents the equilibrium unfished spawning biomass per-recruit.

### *Parameter estimation*

The objective function was simply the product of the negative log-likelihood function and prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log-likelihood function for the survey and fishery catch at age data (in numbers):

$$f = n \cdot \sum_{a,t} p_{at} \ln\left(\hat{p}_{at}\right) ,$$

$$p_{at} = \frac{O_{at}}{\sum_a O_{at}}, \qquad \hat{p}_{at} = \frac{\hat{C}_{at}}{\sum_a \hat{C}_{at}}$$

$$\hat{C} = C \cdot E_{ageing}$$

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix} ,$$

where *A,* and *T,* represent the number of age classes and years, respectively, *n* is the sample size, and $O_{at}$, $\hat{C}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For model runs presented above, we assumed that ageing error was insignificant. Sample size values were fixed at values shown in Table 1.10. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, it is well known that the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A}\prod_{t=1}^{T}\frac{\left(\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\tau^2}\right\}+0.01\right)}{\sqrt{2\pi\left(\eta_{t,a}+0.1/T\right)}\tau}$$

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$-1/2\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left(2\pi\left(\eta_{t,a}+0.1/T\right)\right)-\sum_{a=1}^{A}T\log_e(\tau)$$
$$+\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left[\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\tau^2}\right\}+0.01\right]$$

where $\eta_{t,a} = \hat{p}_{t,a}\left(1-\hat{p}_{t,a}\right)$

and $\tau^2 = 1/n$

gives the variance for $p_{t,a}$

$$\left(\eta_{t,a} + 0.1/T\right)\tau^2 .$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered “outliers.”

Within the model, predicted survey abundance accounted for within-year mortality since surveys occur during the middle of the year. As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant).

Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$\hat{N}^s_{t,a} = e^{-0.5Z_{t,a}} N_{t,a} q^s_t s^s_{t,a}$$

where the superscript *s* indexes the type of survey (EIT or BTS). For these analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the EIT and bottom trawl surveys). The contribution to the negative log-likelihood function from the surveys is given by

$$\sum_{t^s} \left( \frac{\ln\left( A^s_{t\cdot} / \hat{N}^s_{t\cdot} \right)^2}{2\sigma^2_{t^s}} \right)$$

where $A^s_{t\cdot}$ is the total (numerical) abundance estimate with variance $\sigma^2_{t^s}$ from survey *s* in year *t*.

The contribution to the negative log-likelihood function for the observed total catches ($O_{t\cdot}$) by the fishery is given by

$$\lambda_c \sum_t \left( \log\left( O_{t\cdot} / \hat{C}_{t\cdot} \right)^2 \right)$$

where $\lambda_c$ represents prior assumptions about the accuracy of the observed catch data. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include $\lambda_\varepsilon \sum_t \varepsilon_t{}^2 + \lambda_\gamma \sum_{ta} \gamma_{t,a}{}^2 + \lambda_\delta \sum_t \delta_t{}^2$ where the size of the *λ's* represent prior assumptions about the variances of these random variables. For the model presented below, over 698 parameters were estimated. Most of these parameters are associated with year-to-year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in-variables, the reader is referred to Schnute (1994). To easily estimate such a large number of parameters in such a non-linear model, automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest. The approach we use to solve for $F_{msy}$ and related quantities (e.g., $B_{msy}$, MSY) within a general integrated model context was shown in Ianelli et al. (2001).

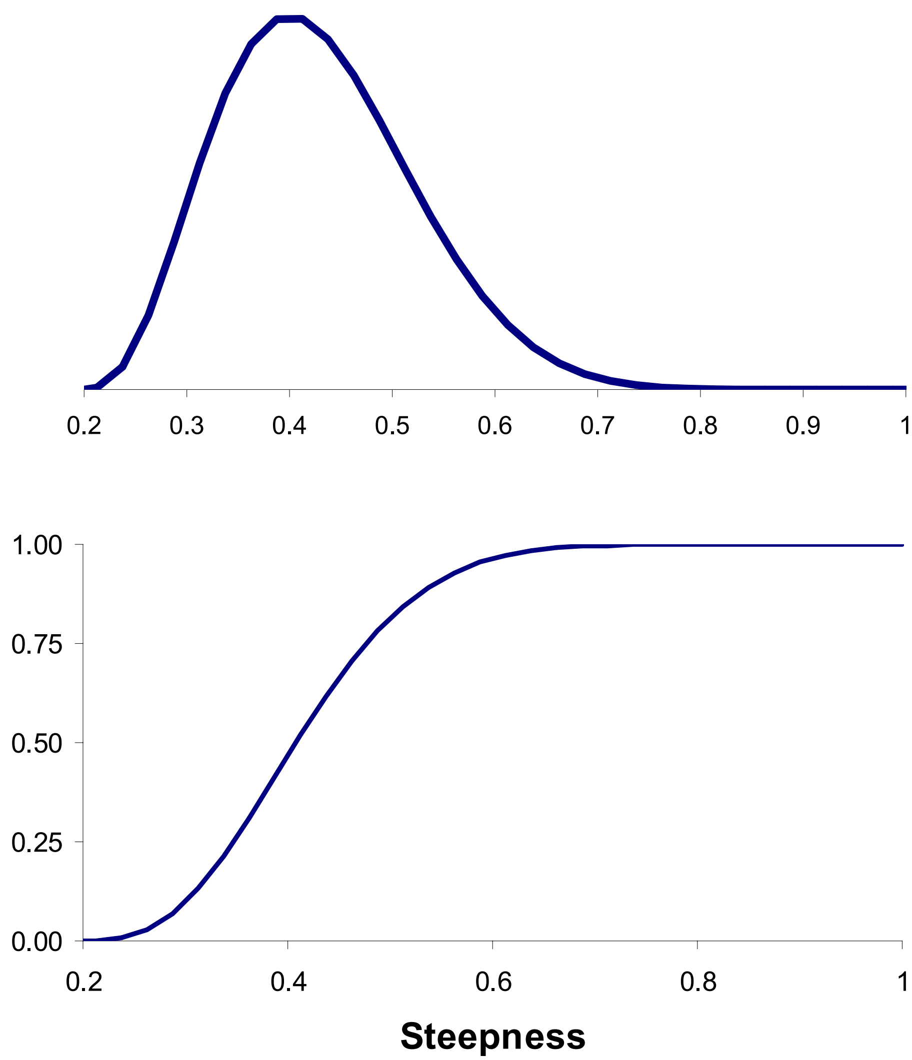



Figure 1.39. Cumulative prior probability distribution of steepness based on the beta distribution ($\alpha$=4, $\beta$=10) assumed for the main model.

## 1.15. Aleutian Island Region Pollock

Although we consider pollock in the Aleutian Island region an operational "stock" for management, the stock definition for "Aleutian Islands pollock" is confounded with Bering Sea abundance levels and abundance in the Aleutian Basin. Since pollock are continuously distributed from the eastern Bering Sea through the Aleutian Islands, it is likely the pollock in the eastern Aleutian Islands are not a discrete stock.

In Ianelli et al. (1997) a preliminary age-structured model for this region was developed and presented. This work revealed that there are interpretation difficulties in distinguishing catches and dynamics from the EBS stock. For example, those results indicated that the stock is likely to be considerably higher than the estimates based on the summer bottom-trawl surveys. Also, since the fishery selectivity estimates were for consistently older pollock compared to the EBS shelf region, the sustainable fishing mortality rates (e.g., $F_{40\%}$ ) were higher (since the fish available to the fishery had had several spawning opportunities). This year we continued to develop the Aleutian Islands age-structured model using the most recent data. Results were similar to what was found before. In the coming year we hope to add some age composition estimates from the surveys. Additionally we will evaluate alternative methods to deal with the problem of uncertain stock-definition. In this assessment we continue as before and evaluate the stock and ABC considerations based on a conservative estimate of natural mortality applied to a conservative biomass estimate (based on the bottom trawl surveys).

Survey effort in the Aleutian Islands region has not been as extensive as in the eastern Bering Sea. The National Marine Fisheries Service in conjunction with the Fisheries Agency of Japan completed bottom trawl surveys for the Aleutian Islands region (from ~165 W to ~170 E) in 1980, 1983, and 1986. The Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division (RACE) conducted bottom trawl surveys in this region in 1991, 1994, 1997, 2000, and 2002. The earlier joint trawl surveys resulted in biomass estimates between 309 and 779 thousand tons (mean 546) for the three surveys. The most recent five RACE surveys resulted in biomass estimates between 117 and 357 thousand tons (mean 188; Table 1.20). We believe that the biomass estimates from the early surveys are not comparable with the biomass estimates obtained from the RACE trawl surveys. In the early surveys, biomass estimates were computed using relative fishing power coefficients (RFPC) and were based on the most efficient trawl during each survey. Such methods will result in pollock biomass estimates that are higher than those obtained using standard methods employed in the RACE surveys. The effect of these early survey estimates will be part of next year's evaluation using the age-structured analysis.

Table 1.20. Pollock biomass estimates from the Aleutian Islands Groundfish Survey, 1980 -2002.

| | Aleutian Region (170E-170W) | Unalaska-Umnak area (~165W-170W) | Combined |
|---|---|---|---|
| **1980** | 252,013 | 56,732 | 308,745 |
| **1983** | 495,982 | 282,648 | 778,666 |
| **1986** | 448,138 | 102,379 | 550,517 |
| | | | |
| **1991** | 128,445 | 51,644 | 180,089 |
| **1994** | 77,503 | 39,696 | 117,199 |
| **1997** | 93,512 | 65,400 | 158,912 |
| **2000** | 105,554 | 22,462 | 128,016 |
| **2002** | 175,283 | 181,334 | 356,617 |

The RACE Aleutian Islands bottom trawl (AIBT) surveys indicate that most of the pollock biomass has been located in the Eastern Aleutian Islands Area (INPFC Area 541) and along the north side of Unalaska-Umnak Islands in the eastern Bering Sea region (~165 W and 170 W). The 2002 Aleutian Islands trawl survey showed that the greatest densities and estimated biomass occur in the Unalaska-Umnak area in the eastern Bering Sea region. Within the Aleutian Islands Region (INPFC Areas 541, 542, and 543) the 2002 AIBT survey indicated the highest densities and biomass were in the Central Aleutian Islands Area (INPFC Area 542) followed by the eastern (INPFC Area 541) and western areas (INPFC Area 543). This pattern is unlike the distribution of abundance observed in previous RACE surveys which indicated the highest biomass to be in the Eastern Aleutian Islands area followed by the central and western areas (Fig. 1.40, Fig. 1.41, and Fig. 1. 42). Since the Aleutian Islands trawl survey is a bottom trawl survey that is limited to within the 500 m isobath these biomass estimates do not include mid-water pollock, nor do they include pollock located outside of the 500m isobath. These biomass estimates therefore represent an unknown portion of the total biomass. The biomass in this area may be greater if the on-bottom/off-bottom distribution is similar to that of the eastern Bering Sea.

The 2002 AIBT Survey showed an increase in pollock biomass in the Unalaska-Umnak Area from the 2000 AIBT survey of over 700 percent. Although the 2002 Echo Integration-trawl (EIT) Survey showed an increase in number of pollock in the Umnak Island aggregation from the 2001 EIT survey, the 2002 EIT survey found a slight decrease in the estimated biomass of pollock in the Bogoslof survey area (232,000 tons in 2001 to 227,000 tons in 2002). This is a further decrease from the estimated pollock biomass in the Bogoslof survey area from the 2000 EIT survey (301,000 tons). In the 2002 AIBT survey the pollock size composition for the Unalaska-Umnak area was more comparable to that found in the eastern Bering Sea than the size composition of the Eastern and Central Aleutian Islands areas (Fig 1.43). In the Unalaska-Umnak Area and the eastern Bering Sea the mode was between 450 mm and 500 mm while in the Eastern and Central Aleutian Islands areas the mode was between 570 mm and 630 mm. The pollock size composition in the Western Aleutian Islands area was bimodal with one mode between 430 mm and 470 mm and another between 570 mm and 630 mm. These data indicate that a movement of eastern Bering Sea pollock to the Unalaska–Umnak Islands area may be responsible for the apparent increase in estimated pollock biomass observed in the 2002 Aleutian Islands trawl survey. Previous AIBT surveys (2000, 1997, 1994, and 1991) showed the pollock size composition in the Unalaska-Umnak Area to be similar to that of the Aleutian Islands Region (Fig. 1.44).

The 2002 AIBT survey indicated a strong mode of pollock between 570 and 630 mm for the Aleutian Islands area (Fig. 1.5). Unlike the 2000 and 1994 AIBT surveys there were few fish observed between the 100 and 250 mm range, indicative of 1 or 2 year old fish. The large numbers of 1 or 2 year old size pollock observed in the 1994 and 2000 surveys were assumed to have entered the fishable population in 1996 and 2002, respectively, and stabilized or increased pollock biomass in the Aleutian Islands in recent years. Due to the closure of the directed pollock fishery in Aleutian Islands region for the past four years, catch-age data for Aleutian Islands region pollock are relatively scarce. In 2001 there were no catch-age data available from the Aleutian Islands region. Since 1998 total catch in this area has been around 1000 tons annually.

Although a limited number of age-structured model runs were done on this stock in the past, the results showed a large degree of ambiguity. Consequently, until the issues of stock definition and survey interpretation are resolved, we recommend continuing the use of the most recent survey biomass estimate applied to an adjusted natural mortality to obtain the ABC and OFL. The Unalaska-Umnak Islands area in the Eastern Bering Sea region was considered in this assessment because this area was surveyed as part of the Aleutian Islands bottom trawl surveys, and was never included in the eastern Bering Sea trawl surveys. However, we do not believe it is appropriate to include biomass from the Unalaska-Umnak Islands area in the Aleutian Islands region estimates, because pollock in that area are included in the eastern Bering Sea catch and assessed via catch-age models.

The 2002 AIBT survey estimated biomass at 175.28 thousand t for the Aleutian Islands regions west of $170^0$ W, a 66 % increase over the 2000 survey estimate of 105.55 thousand t (Table 1.21). This gives an ABC based on Tier 5 (2002 AIBT survey biomass $\times M \times 0.75$) of **39,438 t** at a biomass of 175,283 t (with $M = 0.3$). The OFL based on Tier 5 (2002 AIBT survey biomass $\times M$) gives **52,585 t**.

| | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | F |
|---|---|---|---|---|---|---|---|
| $F_{ABC}$ | 17,413 – 28,000 t | 23,760 t | 23,760 t | 23,760 t | 23,750 t | 39,434 t | 0.225 = 0.75 M |
| $F_{OFL}$ | 24,000 – 38,000 t | 31,680 t | 31,680 t | 31,680 t | 31,666 t | 52,585 t | 0.3 = M |

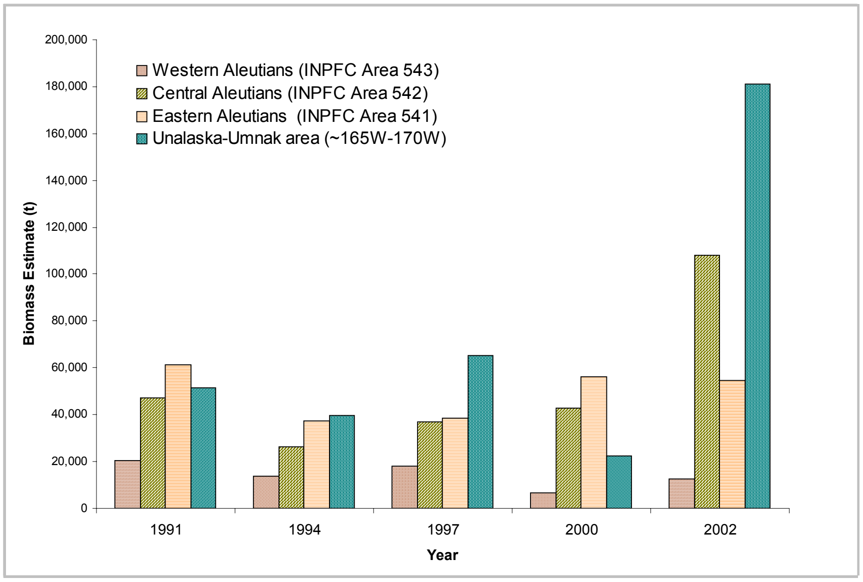



Figure 1.40. Pollock biomass estimates from the Aleutian Islands bottom trawl surveys by area, 1991 - 2002.

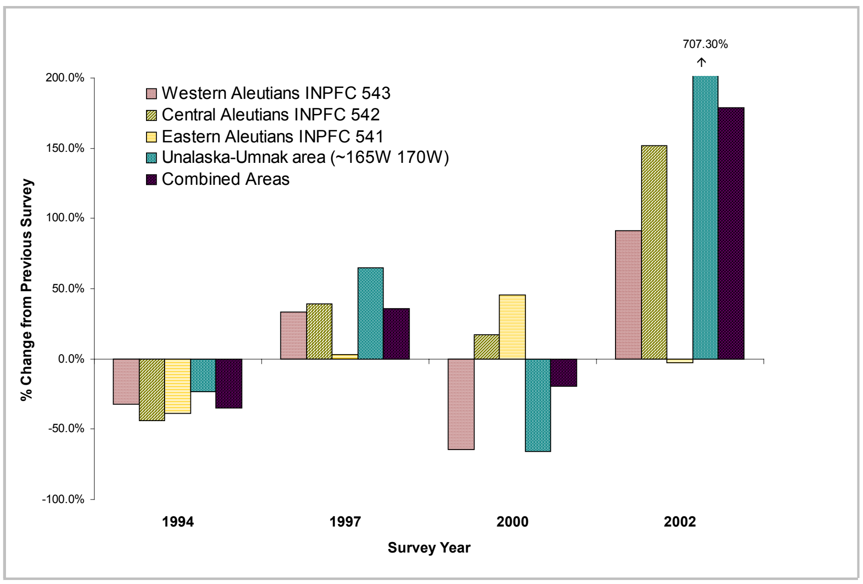



Figure 1.41. Change in pollock biomass estimates from previous Aleutian Islands bottom trawl surveys, 1991-2002

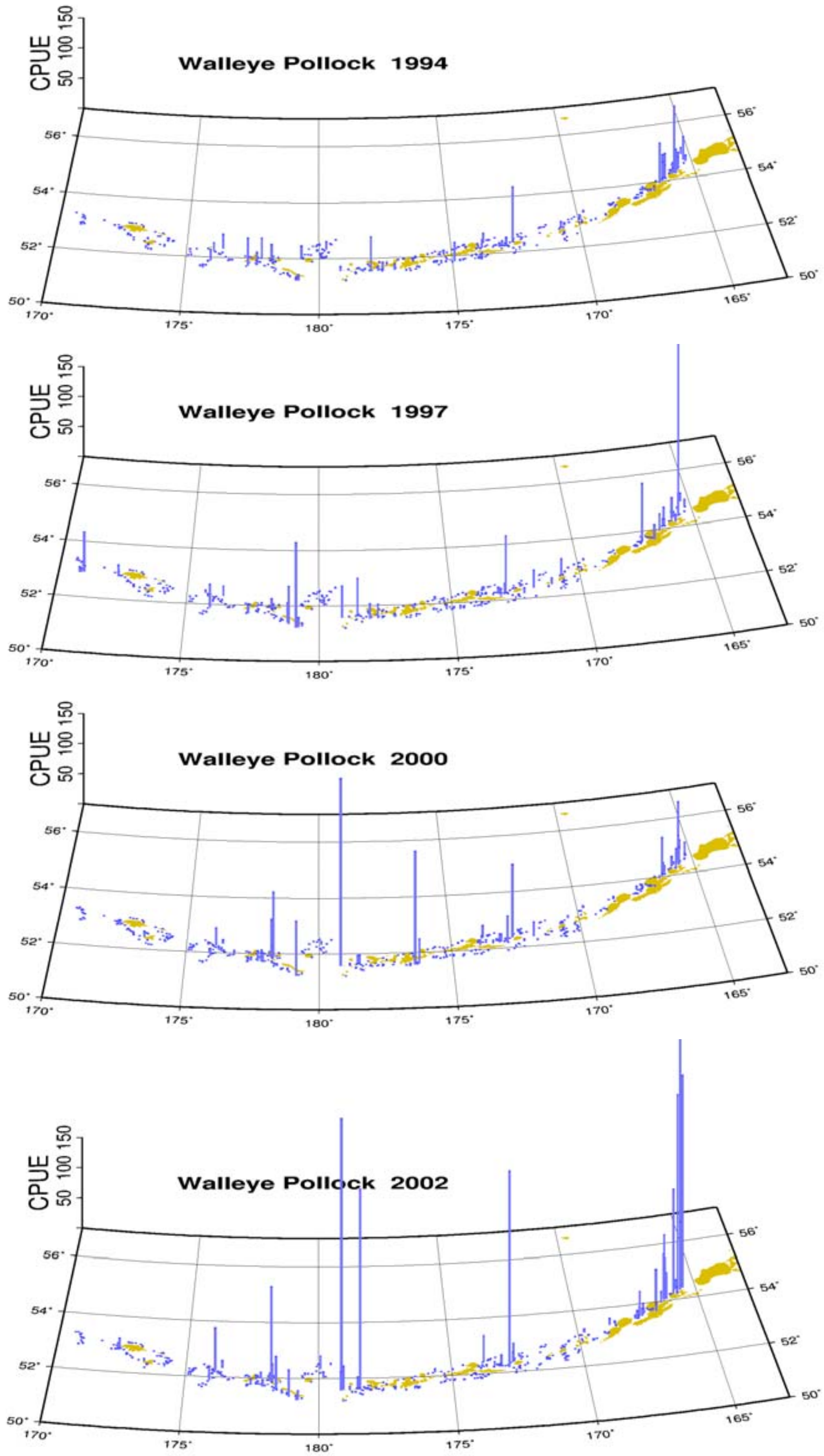



Figure 1.42. NMFS survey distributions of pollock in the Aleutian Islands region, 1994 - 2002. The height of the vertical bars is proportional to survey station pollock catch rate.

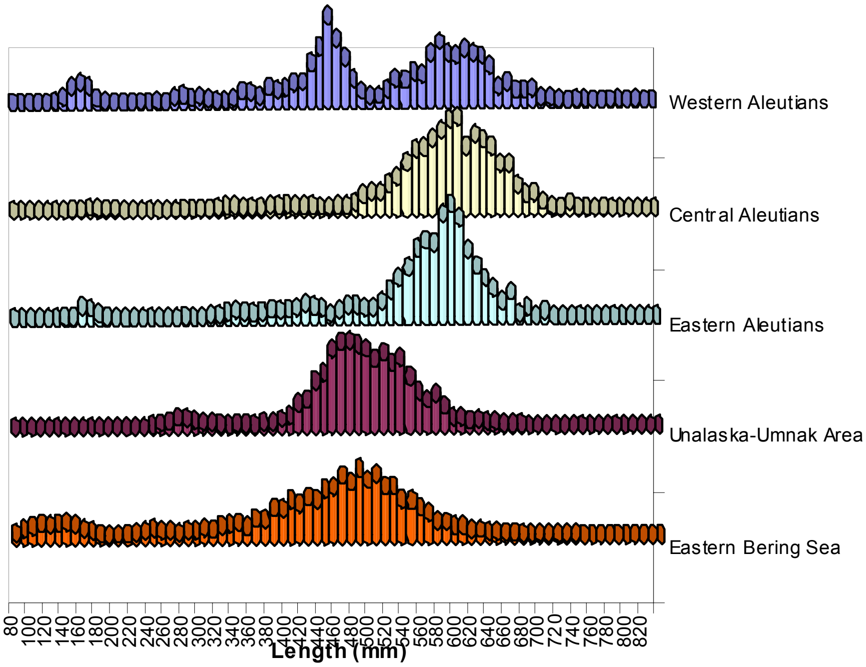



Figure 1.43. Pollock size compositions by proportion of total at length category from the 2002 Aleutian Islands bottom trawl survey and 2002 eastern Bering Sea trawl survey.

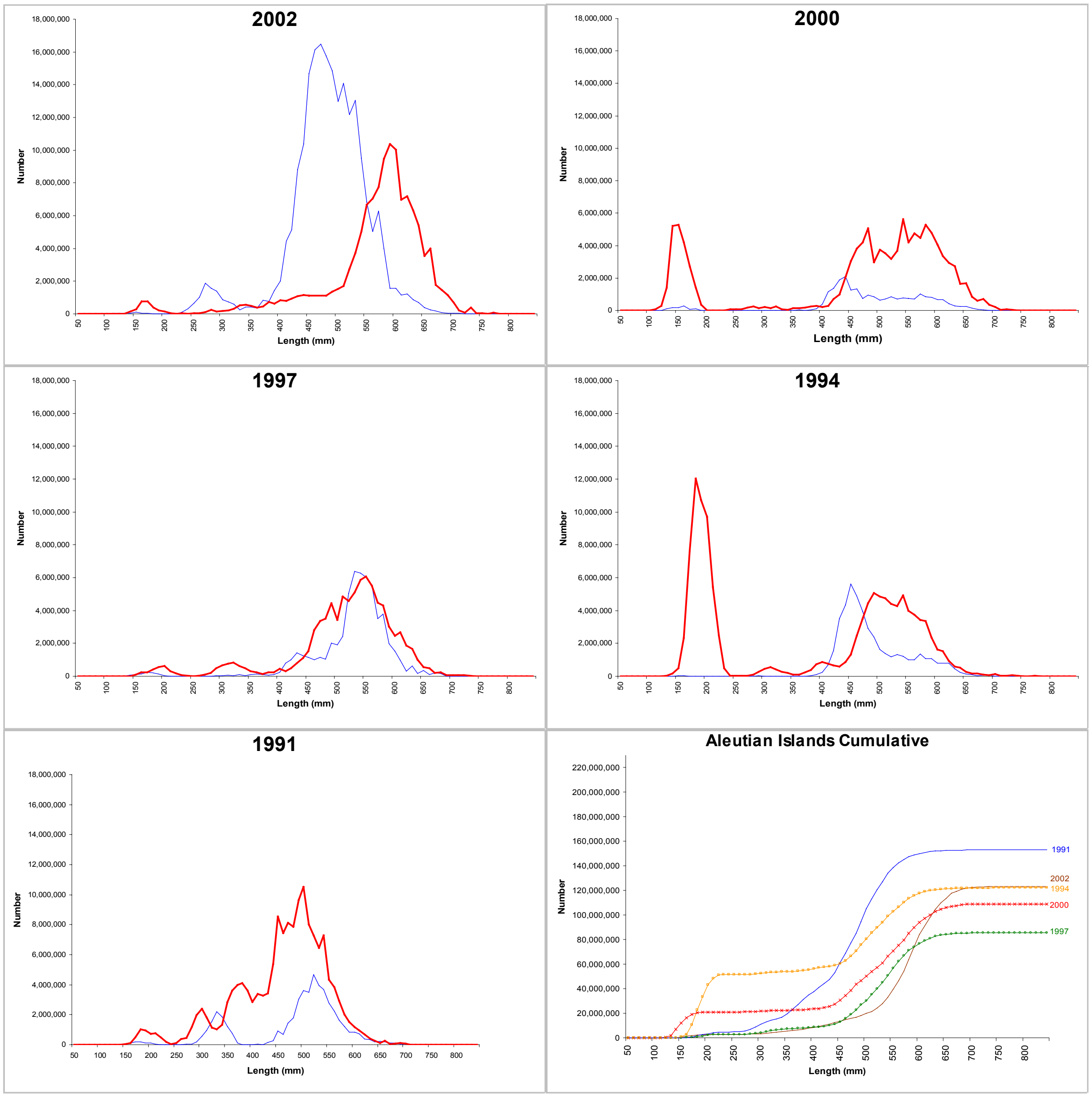



Figure 1.44. Size composition of pollock from Aleutian Islands bottom trawl surveys 1991-2002. The thick line represents the Western, Central, and Eastern Aleutian Islands (INPFC Areas 541-543) and the thin line represents the Unalaska-Umnak Area (165W-170W ).

## 1.16. Aleutian Basin-Bogoslof Island Area

Since 1999 we have presented 2 alternative methods for computing ABC values for the Bogoslof region. They include:

1. The same method as in past years (with 2,000,000 ton estimate for $B_{40\%}$)
2. The same method as is currently used for the Aleutian Islands region (i.e., Tier 5, $F_{ABC}$ =0.75*M)

In 1999 we proposed a third method: a simplified age-structured model based on recent Bogoslof population trends. The Council SSC considered the age-structured model to be inappropriate since it covered only part of the stock and concurred with the Plan Team on placing Bogoslof pollock in Tier 5. In 1999 the Council SSC also recommended reducing the ABC value based on the historical target for biomass in this region (2 million tons). This year we present the two Council SSC approved calculations for estimating the ABC for this region.

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish belong to the same "stock". The pollock found in our surveys are generally older than age 5 and are considered distinct from eastern Bering Sea pollock. Data on the age structure of Bogoslof-Basin pollock show that a majority of pollock in the Basin originated from year classes that were also strong on the shelf, 1972, 1978, 1982, 1984, 1989, 1992, and 1996. There has been some indication that there are strong year classes appearing on the shelf that have not been coincidentally as strong (in a relative sense) in the Bogoslof region (Ianelli, et al 2001). The conditions leading to strong year classes of pollock in the Basin appears to be density related and may be functionally related to abundance on the shelf.

Differences in spawning time and fecundity have been documented between eastern Bering Sea pollock and Aleutian Basin pollock. Pollock harvested in the Bogoslof Island fishery (Area 518) have noticeably different age compositions than those taken on the eastern Bering Sea shelf (Wespestad and Traynor 1989). Pollock in the northern shelf have a similar size at age as Aleutian Basin pollock although a very different age composition. However, Aleutian Basin pollock may not be an independent stock. Very few pollock younger than 5 years old have ever been found in the Aleutian Basin including the Russian portion. Recruits to the basin are coming from another area, most likely the surrounding shelves either in the US or Russian EEZ.

### 1.16.1. ABC estimates for Bogoslof area

The National Marine Fisheries Service has conducted echo-integration-trawl (EIT) surveys for Aleutian Basin pollock spawning in the Bogoslof Island area annually since 1988, with two exceptions: a Bogoslof Island area EIT survey was not conducted in 1990 and the 1999 Bogoslof Island area EIT survey was conducted by the Fisheries Agency of Japan. The annual Bogoslof Island area EIT survey results (Fig 1.45) show that population decline occurred between 1988 and 1994, and then increased in 1995. The movement of pollock from the 1989 year class to the Bogoslof Island area was partly responsible for the 1995 increase (Fig. 1.46), but the abundance of all ages increased between 1994 and 1995. The decrease between 1995 and 1996 was followed by a continued decline in 1997. This suggests that the 1995 estimate may have been over-estimated, or that conditions in that year affected the apparent abundance of pollock. A small increase in estimated biomass in 1998 was followed by a continued decline in the 1999, 2000, 2001, and 2002 surveys. The current population levels on the eastern Bering Sea shelf, and the absence of extremely large year classes, suggests that pollock abundance will not increase significantly in the Bogoslof area in the coming years. The 1989 year class remains the predominant year class in the Bogoslof area. The 2002 Bogoslof Island EIT survey results have been published as an AFSC Processed Report (Honkalehto, et al 2002). The summary Bogoslof Island area EIT survey biomass estimates, 1988-2002, are as follows:

| Biomass (million t) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
| 2.4 | 2.1 | - | 1.3 | 0.9 | 0.6 | 0.49 | 1.1 | 0.68 | 0.39 | 0.49 | 0.48 | 0.30 | 0.23 | 0.23 |

Tier 5 computations use the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC (2001 survey biomass $\times M \times 0.75$) of **33,982 t** at a biomass of 226,548 t (with $M = 0.2$). The OFL is **45,309 t**.

Given the survey estimate of exploitable biomass of 0.232 million t and M = 0.2 and based on the SSC discussions for further reductions in ABC based on considerations of a target stock size of 2 million tons, the $F_{ABC}$ recommendation is computed as:

$$F_{abc} \leq F_{40\%} \times \left(\frac{B_{2002}}{B_{40\%}} - 0.05\right) \Big/ (1-0.05) = 0.27 \times \left(\frac{226{,}000}{2{,}000{,}000} - 0.05\right) \Big/ (1-0.05) = 0.018$$

Using a fishing mortality rate of 0.018 translates to an exploitation rate of 0.018 which when multiplied by 226,548 t, gives a **2002 ABC of 4,074 t for the Bogoslof region.**

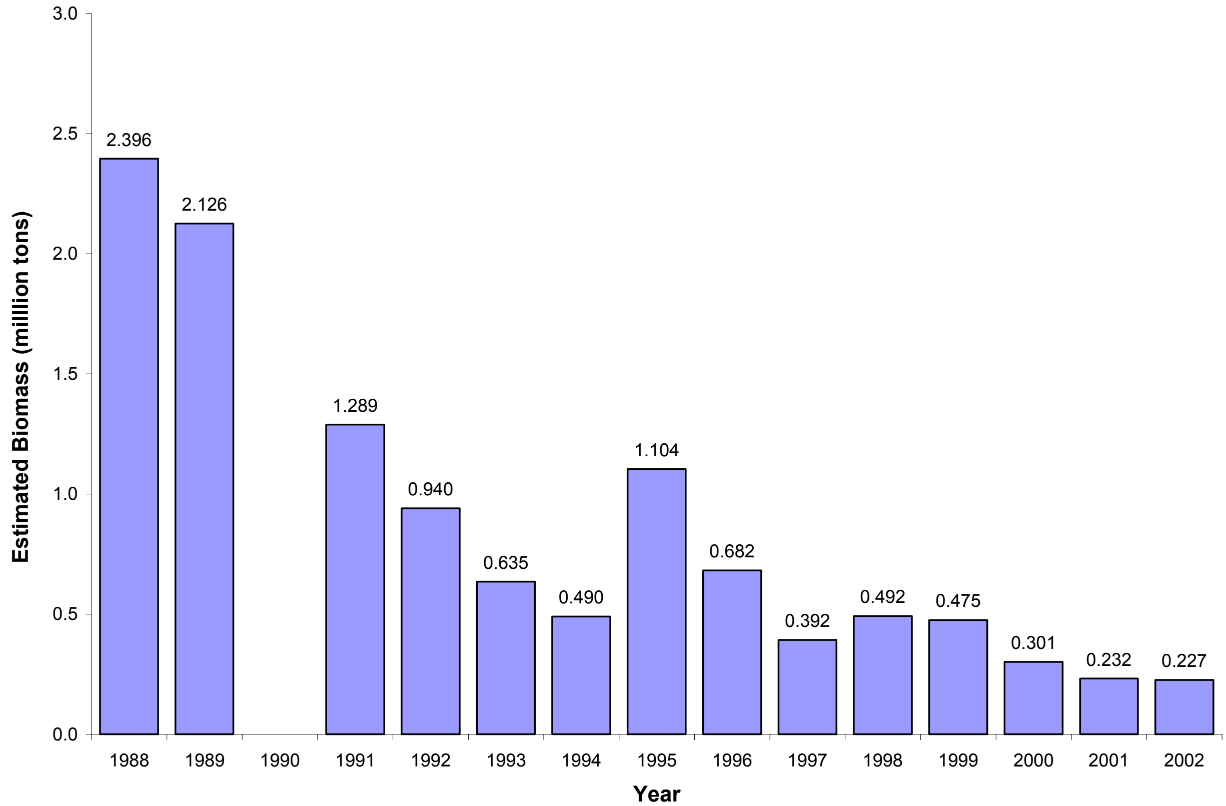



Figure 1.45. Pollock biomass estimates from the 1988-2002 Bogoslof Area EIT surveys in millions of tons. There was no survey in 1990.

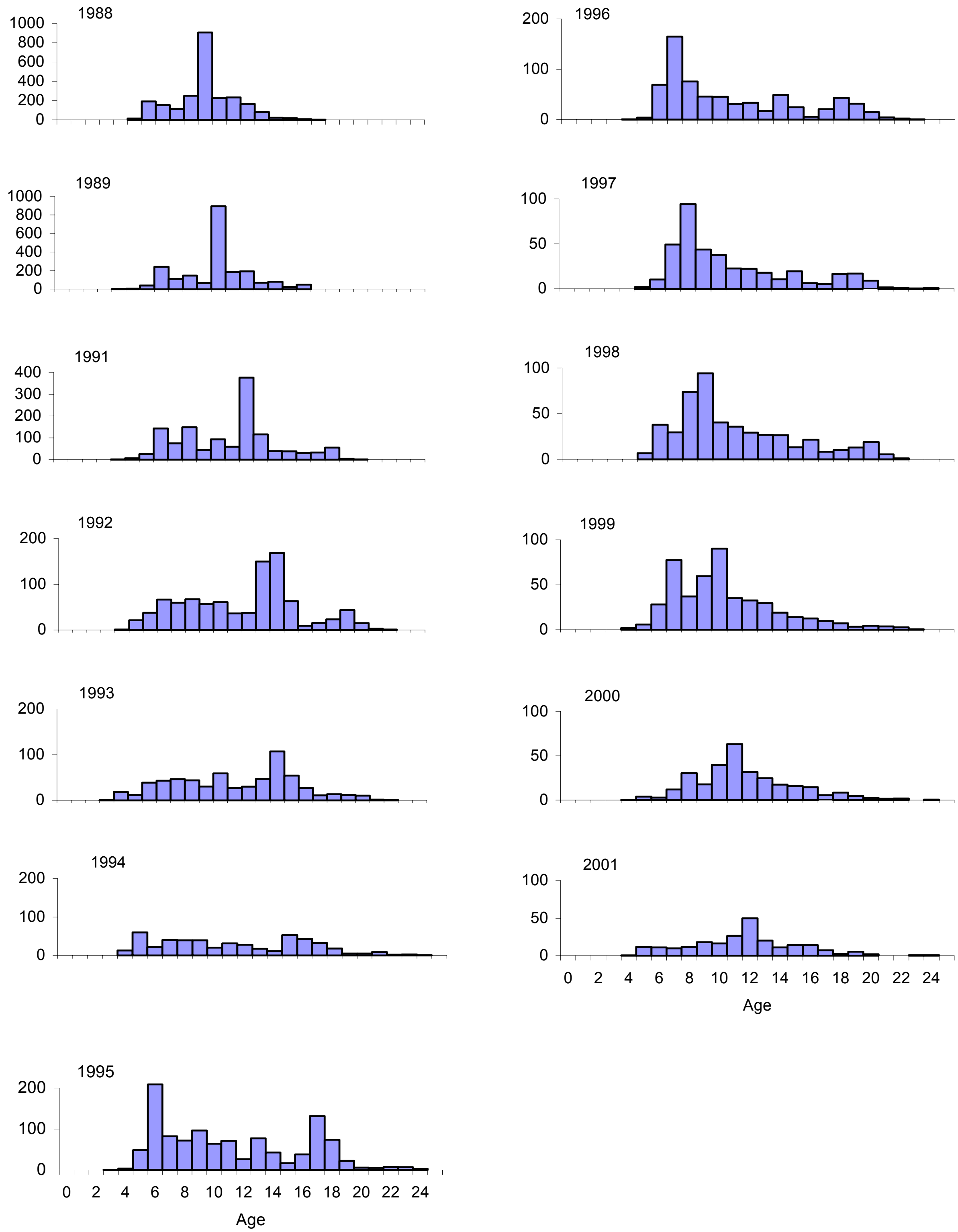



Figure 1.46. Pollock biomass-at-age estimates from the 1988-2001 Bogoslof Area EIT surveys (thousands of mt). There was no survey in 1990. Please note that the y-axis scales differ.